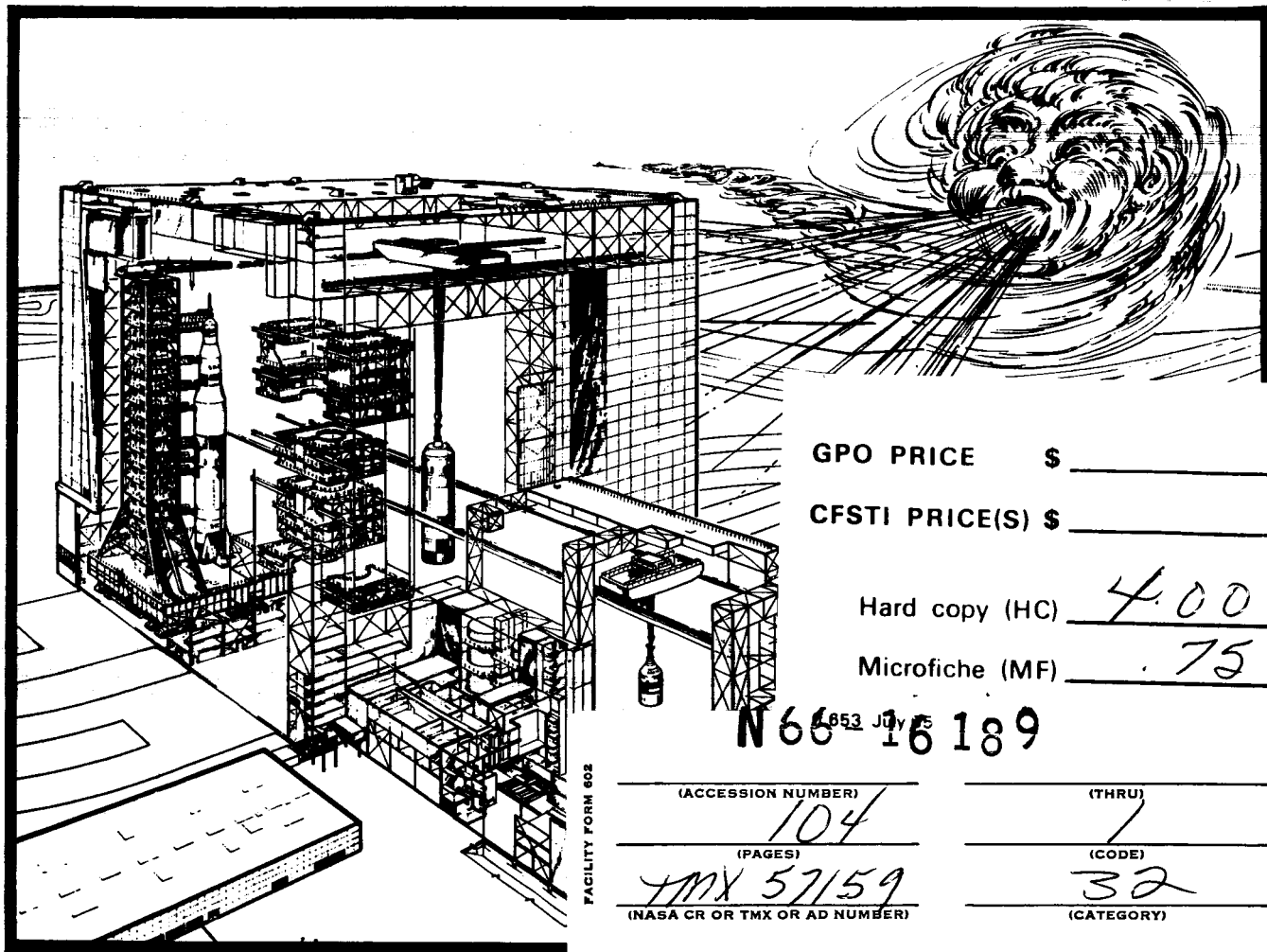


PROBLEM OF LOW LEVEL WIND DISTRIBUTION



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THE PROBLEM OF LOW LEVEL
WIND DISTRIBUTION

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ABSTRACT

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The variation of wind with altitude at low levels is hypothesized to be a universal velocity defect law; the exponential Sherlock formula fitted to observed data and extended to high altitudes is unbounded. Data from Hurricane Cleo 1964 and Dora 1964 is included with data from nine other storm happenings. Averaging of observed data as V^2 function is suggested in lieu of arithmetic averaging of V ; probabilities developed from V^2 statistic (observed anemometer readings) need be transformed in probability to the linear V statistic to obtain high confidence levels at the extremes. Technical comments are solicited to promote math model development.

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NOTICE

The opinions and technical developments and hypotheses presented in this paper are solely those of the author based on his own experience and knowledge; the author encourages free discussion of these options, and hypotheses.



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THE PROBLEM OF LOW LEVEL WIND DISTRIBUTION

by J. H. Deese
assisted by
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I. INTRODUCTION

As a native Florida cracker, I can well remember the severe weather of exceptional thunderstorms and hurricanes. For instance, listening to the thump of our two story frame house as the wind lifted and dropped it again and again to its foundations or watching the shingles and framing of a section of the front porch fly apart and scatter with the sound of a freight train in a rumbling twister, or walking through the residue of a virgin pine forest where a hundred yard width swath of green timber had been twisted into match sticks. In those days of the early 20's, both timely weather warning and adequate structural design were non-existent. Today's Structural Engineering and architecture have as one of their prime purposes the design and construction of facilities to withstand the elements and to protect the people and equipments which they house. I am intensely interested in the development and usage of these practices.

For the past fifteen years I have been intimately associated with the development of Service Structures at Cape Kennedy;

more recently, I am connected with the design and development of concepts employed at NASA Merritt Island Launch Area such as Arming Towers and the Vertical Assembly Building.

In 1951/1952 the first "A frame" service structure was designed and built (Figure 1). It was adapted from the existing oil field portable drill masts. Wind loads were calculated on a constant horizontal wind from top to bottom; the structure height was 147 feet. Incidentally, this structure served Alan Shepherd, our first human astronaut.

In 1956, the second "A frame" structure 112 feet high was ordered (Figure 2). In 1957 a third structure of the inverted U design, but still of the self raising leg type was purchased; its height was 134 feet (Figure 3). All of these structures were designed for reclining stowage in hurricane winds; moments from their erecting loads were greater than those imposed by hurricane winds in the guyed erect position. Overturning design moments without guying were calculated to occur at 55 - 60 knots; this range had been selected as the maximum occurring afternoon thunder squalls. During the summer of 1956 when Structure No. 1 was being used with a Redstone vehicle a 55 mile wind actually rocked the structure; (reminiscent of our old thumping homestead). On an expedited basis, we proceeded to install a guying system to withstand 125 mph hurricanes; our problem was ended.

When planning for Launch Complex 34 was initiated in 1958, design of Service Structure 34 was based on withstanding hurricane force winds (125 mph); practice at that time introduced the Sherlock exponential formula^{1,2}. This structure was 310 feet tall and weighed approximately 6,000,000 lbs (Figure 4). Wind effect was based on overall structure drag factor computed from wind tunnel tests; wind loads were computed from this area coefficient and the Sherlock wind profile with 1/7 exponent.

Essentially the same process was repeated in the design of LC 37 Service Structure which was 303 feet high (top frame) and weighed approximately 10,000,000 lbs (Figure 5). Because of the open framing and cylindrical members, the effect of the Sherlock exponential profile was not significant as compared with the older practice of a constant value profile. This constant profile used the extreme recorded wind number.

When feasibility studies and criteria development was initiated on MILA LC 39 (in June 1962), wind loads were found to seriously affect the Vertical Assembly Building structure; especially, those concepts which envisioned a completely enclosed structure offering weather protection to both the Saturn V space vehicle and the Launcher Umbilical Tower. A preliminary report³ comparing old and new practices presented the problem; but the tight schedule to reach the Moon precluded extensive studies and attempts at extrapolation of weather

data from the 30 ft. U. S. Weather Bureau reference levels to higher altitudes. Our knowledge of the Nature of Low Level Winds (under 1000 ft. altitude) at Cape Kennedy was at that time almost nonexistent.

II. THE PROBLEM

After a number of conferences with national authorities, the Architect Engineer^{4,5} selected a velocity profile for hurricane exposure of the VAB at the MILA site (Figure 6). This profile is representative of the best possible judgement that could be made in the absence of comprehensive data. The factor of two and more by which the current ASCE practice differed from the older flat profile practice was most intriguing. Surely, if no failures existed in actual exposure history of the older designs, either the modern practice or the factors of safety as previously used are overly conservative. If one reviews the literature, he finds a lore of information on the characteristics of frames, members, and shapes when exposed to wind; but an almost complete dirth of information on the Nature of the Low Level Winds at specific locations such as Cape Kennedy and the Merritt Island Launch Area.

As a comparison of the effect of various assumptions for expected extremal conditions, we plotted numbers from ASA and ASCE practices using reference velocities at 30 feet (Figure 7)³; the divergence of these at the higher elevations prompted a consideration of raising the reference level (Figure 8)³. This alone tended to make the numbers easier to live with. The divergence in Figure 8 is still significant, but it is materially reduced from that of Figure 7.

Recalling occasions of previous storm passages, we reconstructed numbers according to memory of various old timers at Cape Kennedy and Patrick Air Force Base. Believing the exponential formula to be the best expression, we compared these numbers as indicated on the curves of Figure 9. The exponent for the fit varies between .19 and .2; suprisingly, compares favorably with the .20 value discussed by Farber and Bell as found by Kamei. Of interest is application of a variety of exponents to the wind number 157 mph when the anemometer at the Jupiter lighthouse blew away in 1934 (?).

Some means was desired by which the variety of exponents applied to the Sherlock formula^{1,2} could be compared (Figure 10). This we did by selecting a hypothetical cantilevered one foot width strip 500 feet high then computing moments and shears for each elevation from the ground up (Figure 11). Of course they all converge at the top, but the relative factors as we get nearer the bottom are extremely divergent; at most by a ratio of 2:1. Continuing the hypothesis as to a phantom cantilevered mast that could withstand such loads, we computed the imaginary weights for such a steel structure (Figure 12). The ratio of the numbers found is alarming; we ask ourselves "Are they truly representative?": - such as 1.34:1; 1.47:1; 1.91:1; and 1.10:1. These precentages when applied to tonnage steel for large structures offers considerable promise that

savings on future construction can be effected and will be of no small value. The major requirement in such problem is that the Nature and Characteristics of Low Level Winds be better defined. Our curiosity had now felt the needle; my own personal desire for rationalization of the problem led into further investigation.

III. GENERALIZED DISCUSSION

A review of flow theory^{6,7,8,9} (Figure 13) showed some promise. In viscous laminar flow both over flat plates and thru pipes, a maximum velocity is found in every instance. If the pipe be of infinite diameter, then like the plate, the maximum or free stream velocity exists in regions of the fluid where the viscous transported drag effect of the wall has become negligible. This condition is true for both laminar and turbulent streams having uniform average velocities. By analogy, there must be a region above the earth's surface where the effects of its roughness on the wind becomes negligible.

An early application of theory developed in the last century resulted in the Ekman spiral (Figure 14).^{2,7,10,11} This function theoretically is limited by the gradient wind and the geostrophic wind. Various derivations by Lamb,⁷ Sutton,¹⁰ and others make certain fundamental assumptions but the end form of the equation is the same. That according to Lamb⁷ is given in Appendix I.

If the maximum number exists, then an expression for the variation of velocity with height must exist such that

$$V_h = V_{(HYP)} \left[1 \pm K_i h / V_{(HYP)} - f(h, V_{(HYP)}, D, \rho_h, \Delta T_h) \right]$$

where:

V_h = Velocity at elevation h ; K_i = Inverse slope of Asympt.

$V_{(HYP)}$ = "X" Intercept of Asymptote to $f(V_h)$ at h of the referenced observation.

Such a function is bounded both by condition of $(V_{(HYP)} \pm K_i h)$ in the free stream and by zero velocity at the surface. Although Sherlock recommends a constant velocity at altitudes above 1000 feet and Kamei above 100 feet when using the exponential formula, the fact is that in

$$V_h = V_{h_0} \left(\frac{h}{h_0} \right)^x ; \left[\begin{array}{l} x \text{ depends on location, and} \\ V_h \rightarrow \infty \text{ as } h \rightarrow \infty \end{array} \right.$$

and the function remains unbounded for $x \neq 0$ except at the surface. Therefore, it is an empirical expression of limited range. The problem remains of obtaining sufficient valid data to establish these limits.

If one inspects flow turbulent theory as now practiced in wind tunnels, the Log Law of the Wall and the Velocity Defect Law are well confirmed. The Law of the Wall^{8,9} is exactly the Sherlock formula with 1/7 exponent; but its region of application is limited to the laminar sublayer. Outside this range, the Velocity Defect Law^{3,9} is receiving extensive investigation. Its fundamental expression is

$$\frac{V_\infty - V_h}{V_\infty} = f(V_\infty, h, \rho_h, \Delta T_h)$$

Definition of the point or range at which the transitions from Log Law to Defect Law occur has yet to be found. It is very likely that the limits of the transition functions can only be

established by modern statistical theory. So far these functions have eluded deterministic approaches.

IV. INSPECTION OF AVAILABLE DATA

For obvious reasons, such as knowing when to anchor down for wind extremes, Service Structures of LC 34 and LC 37 were instrumented with wind measuring devices. Sensing instruments are Bendix Friez Model 120 with frequency response of 60% per sec. Pen Recorders are of two types; Esterline Angus Model 602 and Bendix Friez Model 141. Means is also provided for 1" width MILAR tape recording for computer readout. Chart speeds of pen recorders are selective at 3 inches per hour and 3 inches per minute. Installation of the aerovanes are shown in Figures 15 and 16. Lateral projecting instruments are mounted 8 feet from the structure (Figure 17). Those on top of the structures are mounted at various heights (Figures 18 and 19) above the structures. On top of each Blockhouse, instruments are also mounted (Figure 20).

On the pad in each complex, instruments are mounted on the Pad Light Pole (Figure 21) and on the Umbilical Towers (Figure 22). Unfortunately, there is some question as to the accuracy of these devices because of the structural influence. Moses and Daubek¹² reporting on a tower at Argonne National Laboratory, found that with 9 feet projection of the instruments serious errors occurred in the tower mounted Aerovanes due to a tower influencing effect; both increases by 30% and decreases up to 50% were observed as well as direction deviations up to

40 degrees. Knothe and Callahan (Figure 23) have reported tower influences of a similar nature.¹³ It appears that both wind tunnel model testing and consideration of aerovane proximity to the structure will be necessary to provide a means for correlation confidence in the observed values. Notwithstanding these faults, we have used the instrumentation plans of Figures 24 and 25 for recording eleven instances of extreme weather winds (Figures 26 thru 36). The extreme maximum and minimum are plotted at each level as well as the average for that hour having the highest average and/or for the hour having the highest peak value. In either or both cases, the extremes within the period of record are shown. The data is presented in the following:

Figure 26 Extreme Weather Winds, LC No. 34, 8 February 1964,
0020 to 0120 hours

Figure 27 Extreme Weather Winds, LC No. 37, 8 February 1964,
0030 to 0130 hours

Figure 28 Extreme Weather Winds, LC No. 37, 18 February 1964,
1400 to 1500 hours

Figure 29 Extreme Weather Winds, LC No. 34, 25 February 1964,
1500 to 1600 hours

Figure 30 Extreme Weather Winds, LC No. 37, 25 February 1964,
1420 to 1520 hours

Figure 31 Extreme Weather Winds, LC No. 37, 28 April 1964,
1330 to 1430 hours

Figure 32 Extreme Weather Winds, LC No. 37, 19 May 1964 to
28 May 1964

Figure 33 Extreme Weather Winds, LC No. 37, 27 August 1964,
1545 to 1645 hours, Hurricane "CLEO"

Figure 34 Extreme Weather Winds, LC No. 34, 9 September 1964,
1400 to 1500 hours, Hurricane "DORA"

Figure 35 Extreme Weather Winds, LC No. 37, 9 September 1964,
1310 to 1410 hours, Hurricane "DORA"

Figure 36 Extreme Weather Winds, LC No. 37, 5 October 1964,
1200 to 1300 hours

These data include CLEO 1964 and DORA 1964. Trajectories for these are shown in Figures 37 and 38. Weather predictions of record excluding the hurricanes but regarding the other storm passages are shown in Table I.

During Hurricane DORA, a curious buffetting caused barograph pumping; the barograph was located in a Southwest corner, second floor room of the E&O Building at Cape Kennedy (Figures 39, 40, and 41). I had noticed a surging of the wind in Melbourne during the same time interval and on discussing it with the meteorologist he showed me the record (Figure 42) of the instance. The pen record shows quite clearly the jumping pressure; the solid portion was a continuous pumping. This buffetting at Cape Kennedy could have been caused by vortex shedding from the surrounding buildings¹⁴ since the winds were from the Southwest at that time. However, this

TABLE I

<u>HAPPENING</u>		<u>FORECASTS OF SEVERE WEATHER</u>			
<u>DATE</u>	<u>TIME</u>	<u>DATE</u>	<u>0000</u>	<u>0600</u>	<u>1200</u>
2/8/64	0045	2/6/64		250/10G 20 Kts	240/08 Kts
		2/7/64	180/15G 25 Kts		140/10 Kts
2/8/64	0205	2/7/64		VRBL/5 Kts	270/15 Kts
		2/8/64	240/25G 38 Kts		140/10 Kts
2/16/64	1410	2/15/64			340/10G 25 Kts
		2/16/64	340/10G 25 Kts	330/10G Kts	300/10 Kts
2/17/64	1715	2/16/64			020/10G 15 Kts
		2/17/64	040/10G 15 Kts	030/10G Kts	100/10 Kts
2/18/64	1400	2/17/64			150/10 Kts
		2/18/64	150/10G 15 Kts	210/10G 15 Kts	200/20G 35 Kts
2/22/64	0930	2/21/64			180/15G 25 Kts
2/22/64	1530	2/21/64			VRBL/5 Kts
		2/22/64	050/15G 20 Kts	020/10 Kts	310/10 Kts
2/25/64	1500	2/24/64			020/15G 25 Kts
		2/25/64	130/10 Kts	200/12 Kts	250/20G 35 Kts
					VRBL/5 Kts

does not explain my observation of the pulsing condition some 30 miles away; both sound and eardrum pressure were evidence of the condition. I believe this to have been the nature of the hurricane, not a local condition.

One of the most discussed storms subjected to analysis was Hurricane CARLA 1961 passage through Dallas, Texas, area (Figure 43).¹⁵ The 1400 foot TV tower at Cedar Hill used by station KRLD had been instrumented for acceptance testing. This tower is located on the slope of a Knoll in an area of rolling hills (Figure 44). The entire period was reported by Gerhardt et al.¹⁵ From his figures, the absolute magnitude of the horizontal wind (280 sec. average) was plotted against height. Hourly intervals are shown in Figure 45 together with their time ensembles; ten minute intervals are shown in Figure 46 for that hour having highest winds. The curves indicate both stable flow and transient turbulence in the same storm.

There is some question as to the validity of the instrument measurements at the 1400 foot level. Discarding these does not affect the form of the velocity function of height. In almost all instances, there is a vertical asymptote to $V(h)$. This data confirms that in this instance our model holds where

$$V_h = V_{HYP} \left[1 - f(h, V_{HYP}, D, \rho_h, \Delta T_h) \right]$$

and $V_{HYP} = V_{MAX} ; K_i h \Rightarrow 0$

Again though, the influence of the structure on the observed velocity numbers is not known. The form of the function appears to be well defined. Also, additional data is needed of the actual time trace rather than the 280 sec. averaged values.

V. ATTEMPTED ANALYSES

For the period of September 20, 1963 thru October 1, 1963, an unusual wind condition existed.¹⁶ Point sets of recorded gusts occurring at each level are recorded as gust factor versus five minute averaged speeds in Figures 47, 48, and 49. Both the extreme and the mean show definite convergence with increasing velocity. The lowest level shows the greatest spread of observed gust factors, particularly at the lower speeds. The higher levels show a much lower spread of observed gusts at lower velocities (under 4 m/sec.). Cumulative distribution and density functions are needed for further analysis.

For the 1964 happenings at LC 34 and LC 37, an aggregate of all recorded values was plotted. These aggregates are shown in Figure 50. On the plotted set of the left figure, all sets from the same data happening are connected; on the right figure the points are countably discrete. The sets are normalized to the average velocity squared value at each level. It can be seen that both the sets having values greater than 1 and the set having values less than 1 indicate a convergence near 800 ft. height. Development of this could confirm a generalization of approach suggested by the KRLD tower data.

The cumulative distribution function of all aggregates at all levels

$$P\left(\frac{V_{EXT}^2}{V_{AVG}^2}\right); \begin{cases} (V_{EXT} = V_{MIN}) \\ (V_{EXT} = V_{MAX}) \end{cases}$$

is plotted in Figure 51. The discrete density function of the observed values of the variable are shown below the plots.

The Cumulative Function

$$P\left(\frac{V_{EXT}^2}{V_{AVG}^2}\right)$$

for values below 1.0 is accumulated in the negative direction; for values above 1.0, cumulation is in the positive direction on the abscissa number line. In Figures 52 and 53 the Cumulative Functions

$$P\left(\frac{V_{EXT}^2}{V_{AVG}^2}\right); \quad \frac{V_{MIN}}{V_{AVG}} < 1.0 \text{ and } \frac{V_{MAX}}{V_{AVG}} > 1.0$$

are similarly plotted.

At this reading, the transform to continuous variables representative of these cumulative and density functions has not been completed. However, some conjectures can be made for these observations, such as:

a. The extreme minimum of

$$\left(\frac{V_{MIN}^2}{V_{AVG}^2}\right)_{h_i} < 1.0; \quad h_i [79, 83, 113, 236, 317, 332, 355]$$

for all cases of all levels is never greater than 0.8; and is bounded at 0.

b. The extreme maximum of

$$\left(\frac{V_{MAX}^2}{V_{AVG}^2}\right)_{h_i} > 1.0; \quad h_i [79, 83, 113, 236, 317, 332, 355]$$

for all cases of all levels is never less than 1.02; and is unbounded but is frequency limited with increasing values of

$$\left(\frac{V_{MAX}^2}{V_{AVG}^2}\right) > 1.0$$

Expectancy of any values greater than 12.0 will be very small.

With collection of data from storms yet to come, more definitive analysis on these data and a further inspection of the extremes of point set functions of Figures 47, 48, and 49 correlations can be obtained which will relate the density and cumulative functions of the aggregate to the velocities to be expected at each level. The completion of this effort will, I believe, be a beginning for the comprehensive analysis of Low Level Winds at Cape Kennedy and MILA.

VI. THE NEED FOR NEW APPROACHES

The current practices prescribed by ASCE¹⁴ paper No. 3269 developed from the exponential Sherlock formula provide methods for estimating the winds and gust factors at altitude h ; these average velocity and gust functions are limited to empirical ranges established by observed data. Doubt frequently exists as to the applicable limits of these ranges. Either reinspection should be made of all available data for determining the validity of the Sherlock wind profiles or a new mathematical wind model should be developed along the lines already discussed. The deviation of the average value of the wind at any height from the asymptote to the velocity/height function at that height would then be representative of the maximum gusting that could occur for that particular storm.

The frequency of gusting to any value within this range would be represented by the probability density function for that particular height.

Because the model proposed herein would be developed from the extreme bounds, a correlation is needed between observed velocities for each class of wind storm that can exist and those forecasts of the meteorologist. The structural engineer is actually more interested in the extremes and their behaviour than he is in the predicted average value of velocity associated with the happening. Records showing extremal predicted

values, classifications of the storm genesis, and the general synoptic conditions preceding and during the storm need to be developed. A new statistic is implied.

The cumulative and density distributions of Figures 51, 52, and 53 as well as their aggregates of Figure 50 are all plotted against height (h) and normalized V^2 . Most investigators use normalized V on a linear scale distributed variable. One may ask why we have not also used the linear relationship. The answer lies in elementals of mechanics and probability theory. The Aerovanes are momentum reaction machines; their signal output in most instances is linearly proportional to their speed

$$\text{SIGNAL} = k N; \quad N = \text{rotational speed}$$

As rotating machines, they are not frictionless; the energy to overcome the friction is provided by the sensed wind. Their developed response characteristic (Appendix II) shows relationships to be

$$\frac{1}{k} \cdot \text{SIGNAL} = N = \cancel{K}_{\text{Machine}} \cdot \rho_o \cdot V_o^2 = C_o^2 V_o^2; \quad \left[\begin{array}{l} \text{subscript } o \\ \text{is for observed} \end{array} \right]$$

Therefore, the signal varies directly as the velocity squared.

Since dynamic pressure is also proportional to product of density (ρ_o) times V_o^2 , the signal output must vary directly as p_{dyn} . Then

$$\cancel{K}_{\text{SIGNAL}} \cdot \text{SIGNAL} = N = p_{dyn} = C_o^2 V_o^2$$

or simpler, any observation with an aerovane or anemometer is a V_o^2 function.

In probability theory, the probability functions of variables of order 1 may not be used for their functional equivalents of order $n; (n \neq 1)$ without a transform in probability; also such transform must maintain a 1:1 point relationship for the countable or countably infinite sets. Simply, if a probability function is known for x , and if

$$x = y^2$$

then the $p(x)$ must be transformed by mathematical operations to $p(y)$. For the relationship

$$N = C_0^2 V_0^2$$

a transform method in probability for the two variables is developed in Appendix II. The illustrated case is that when $p(N)$ is gaussian and the developed $p(C_0 V_0)$ is Chi-squared.

Also, in error analysis, the analysis of the primary variable must be limited to the observed quantities. Therefore, the governing distributions for probability development must be limited to deviates in the observation.

Another example would be the average

$$\sum_{i=1}^n \frac{V_i}{n} = V_{AVG} \neq \sqrt{(V_{AVG}^2)} = \sqrt{\frac{\sum_{i=1}^n V_i^2}{n}}$$

By the central limit theorem, V and $\sqrt{V^2}$ are convergent with an infinite set but \bar{V} never equals $(V^2)_{avg}$. in probablistic behavior.

Therefore, the natural statistic should be developed as $f(v^2)$.

The resulting effect is, that for one function, the values of its density at the tail extremes differ by large orders of magnitude from that of its transform functions. Where extremal limits are of such importance as in the wind behavior at low levels, the expected values of extremes of particular happenings can be seriously misestimated, even with the most rigorous arithmetic.

Surely, a new approach and development of new models of the low level wind behavior is indicated.

The commentaries of all reviewers are welcomed to promote the search and development of these models.

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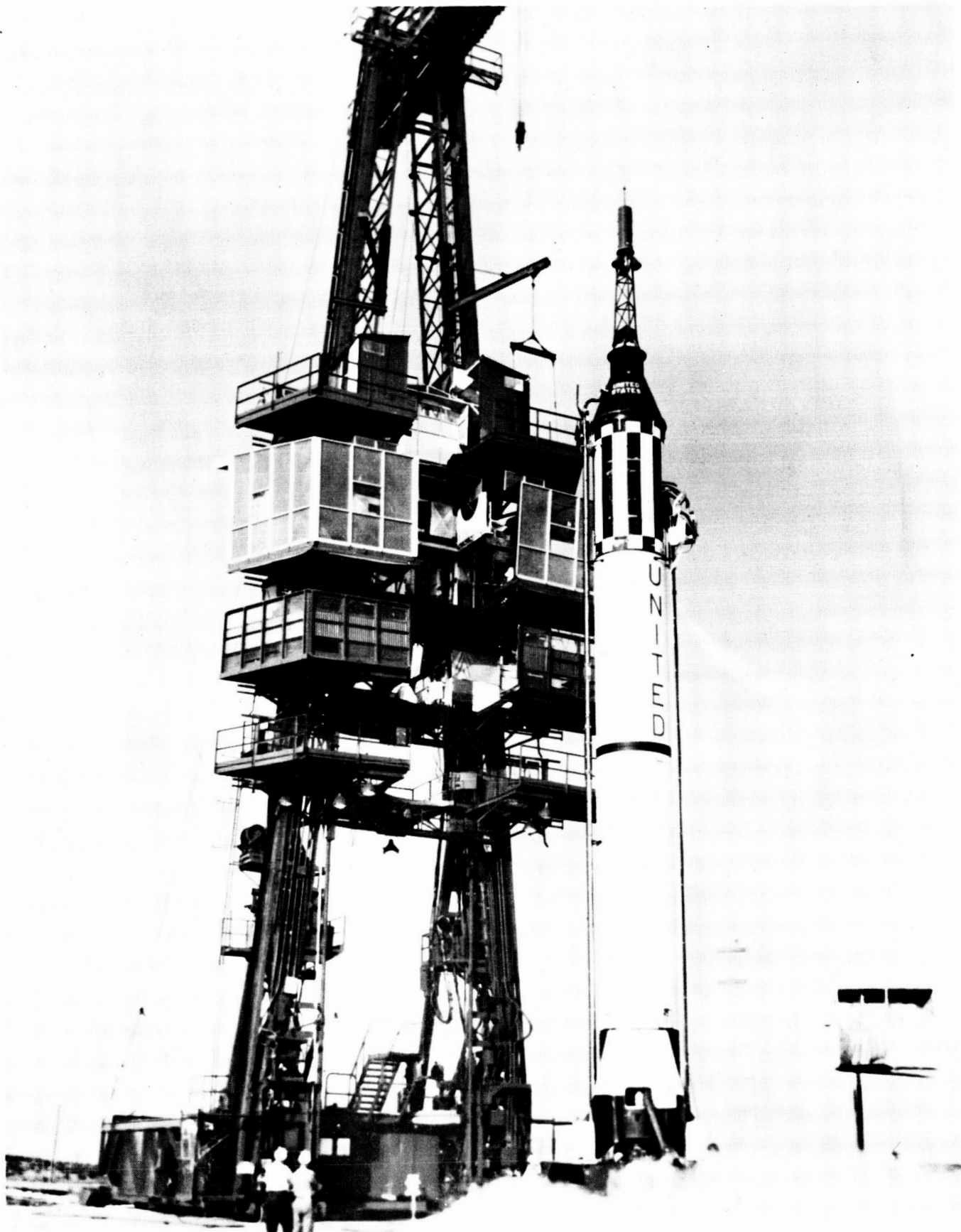


Fig. 1

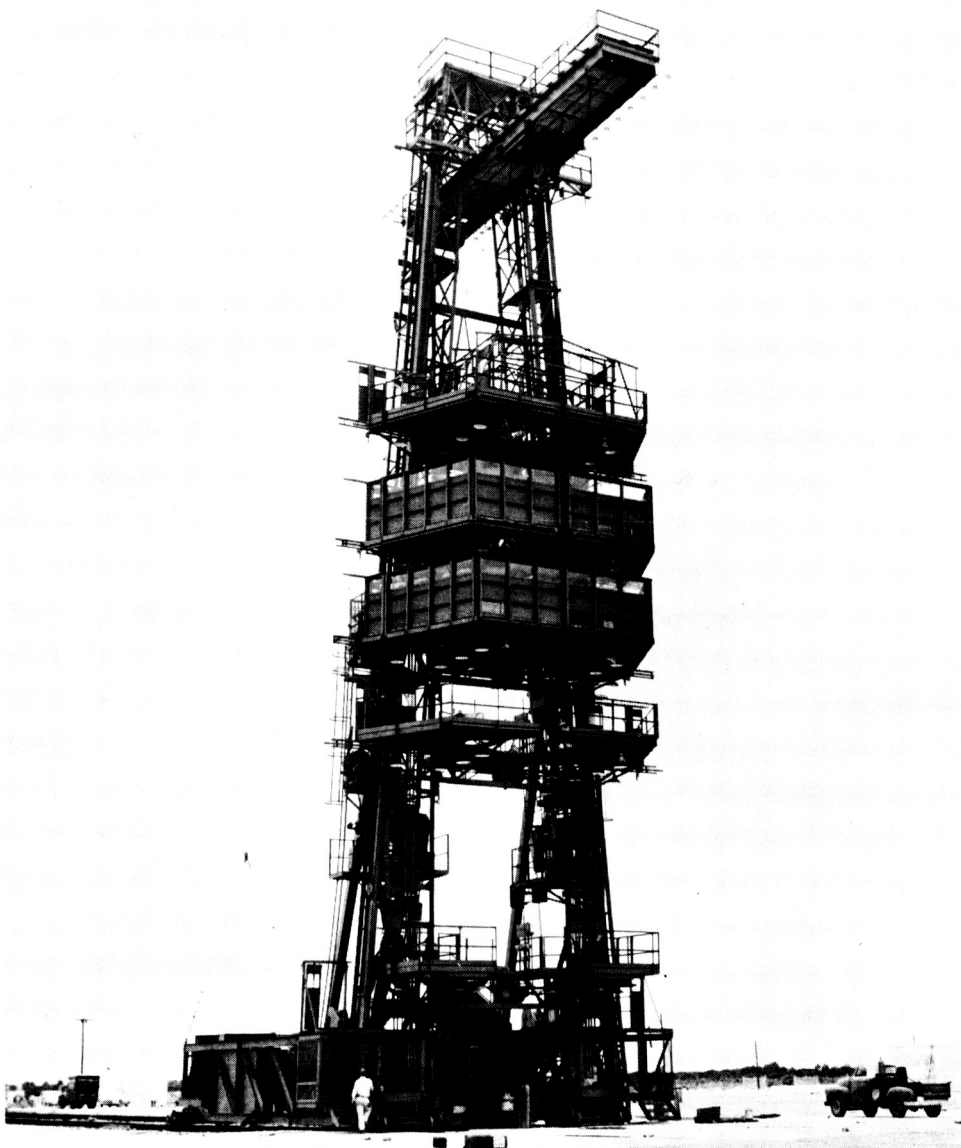


Fig. 2

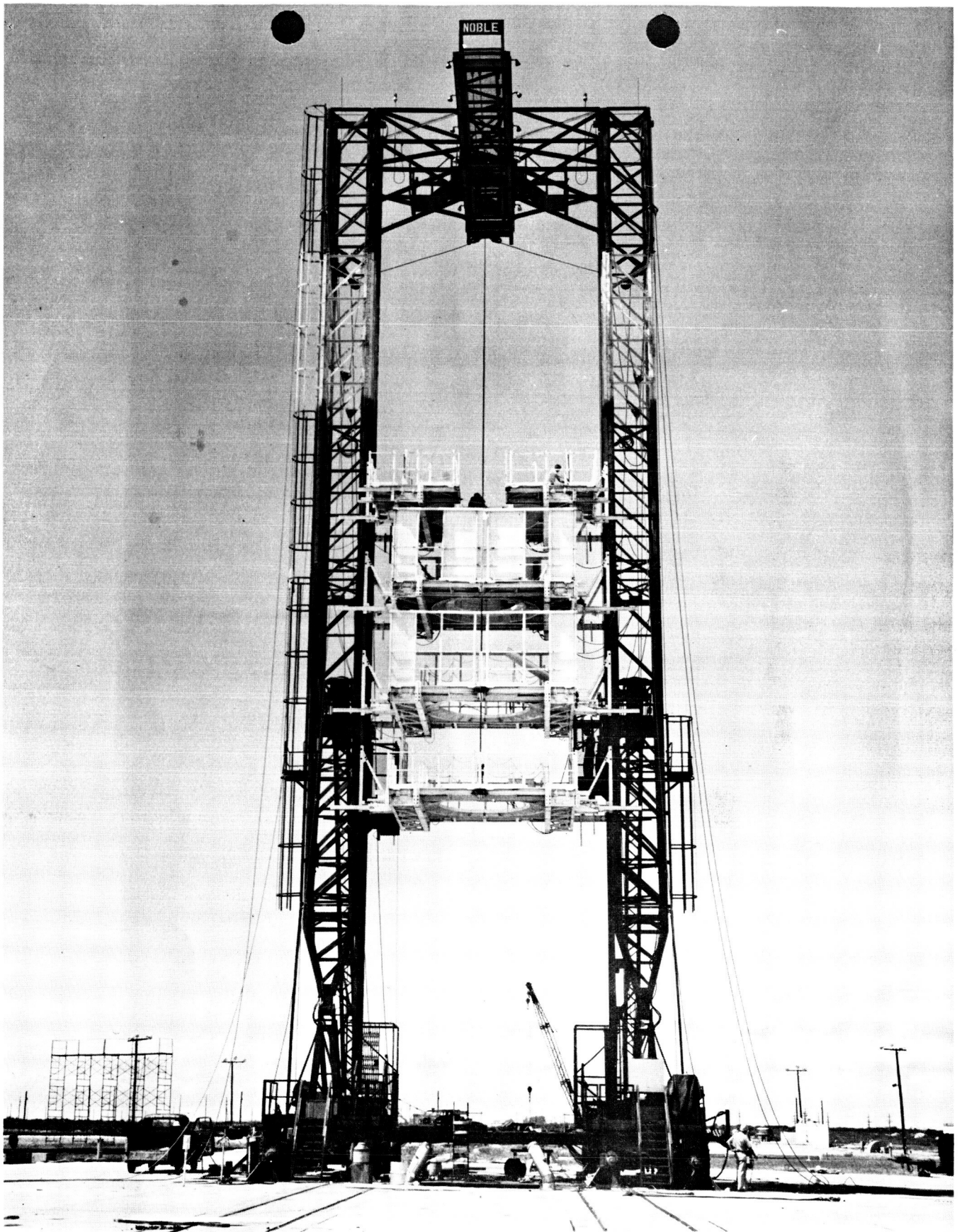


Fig. 3



Fig. 4

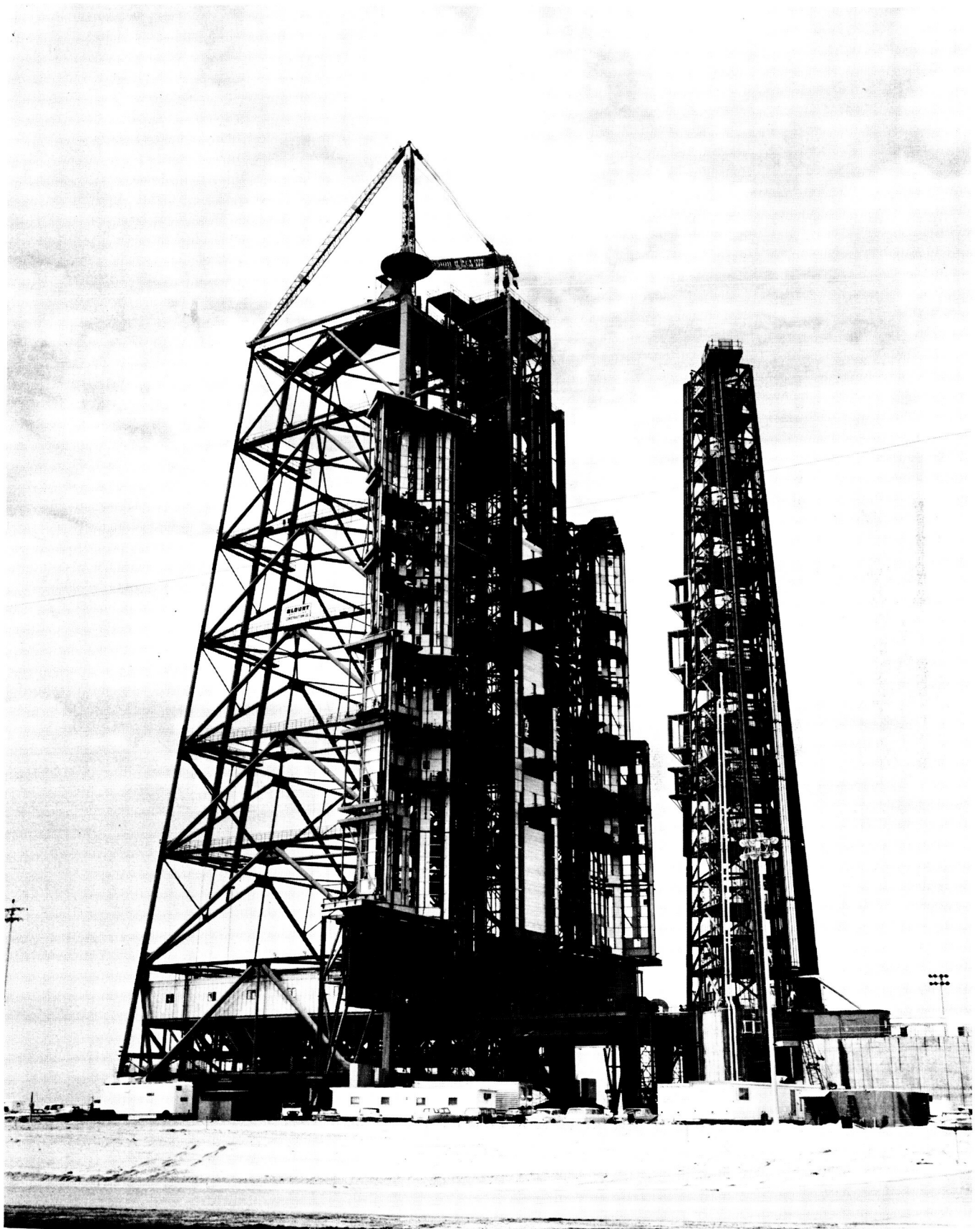


Fig. 5

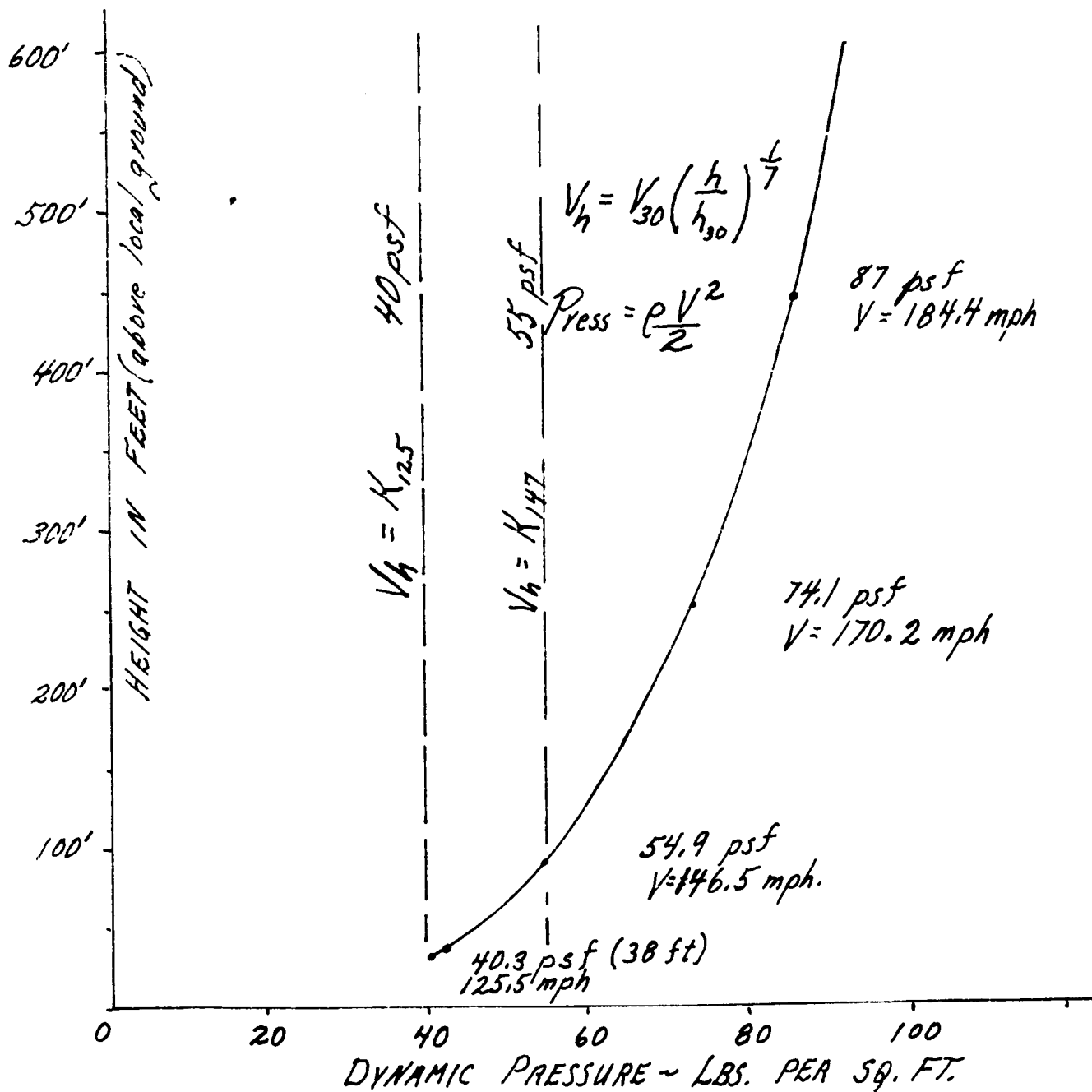


Fig. 6

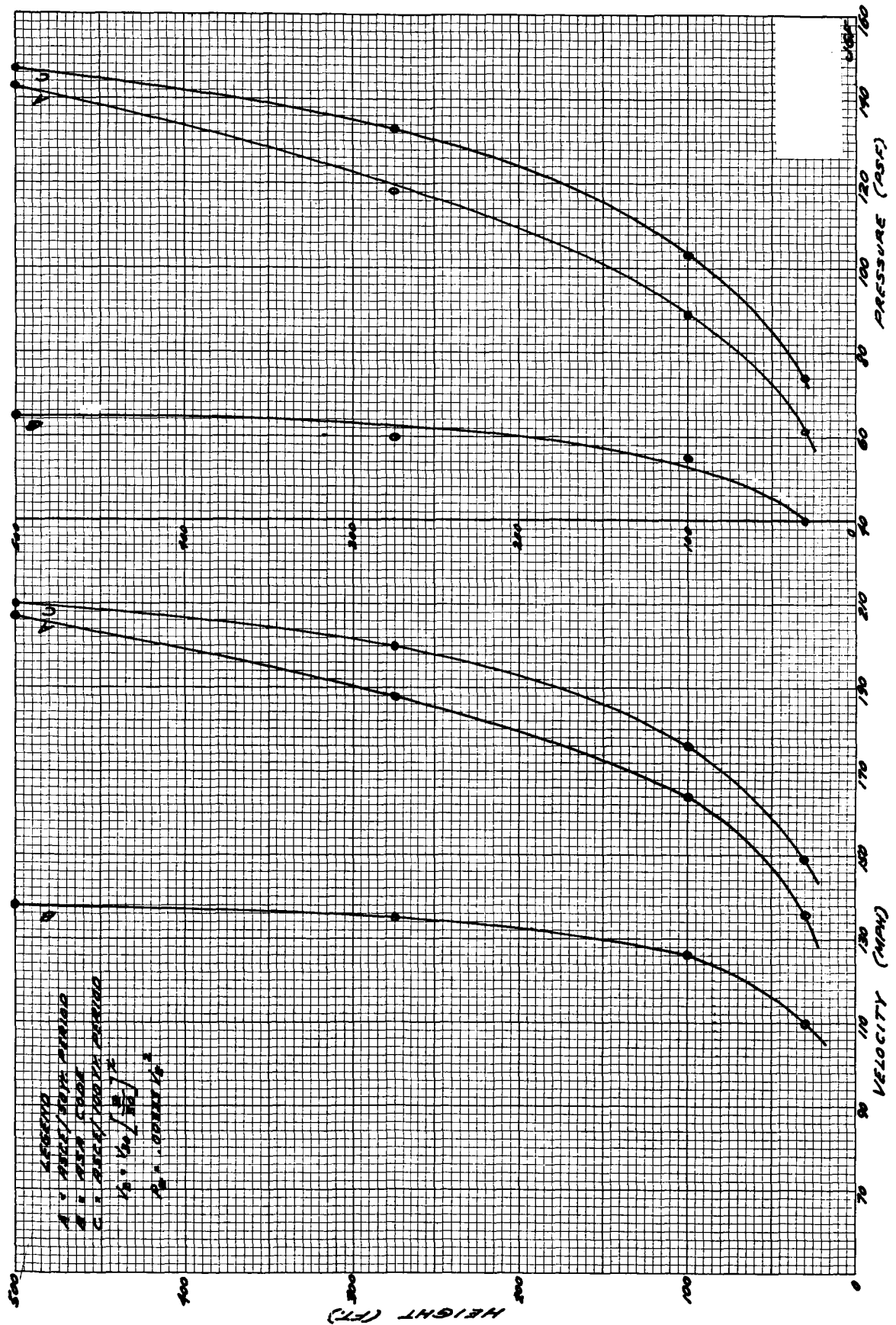


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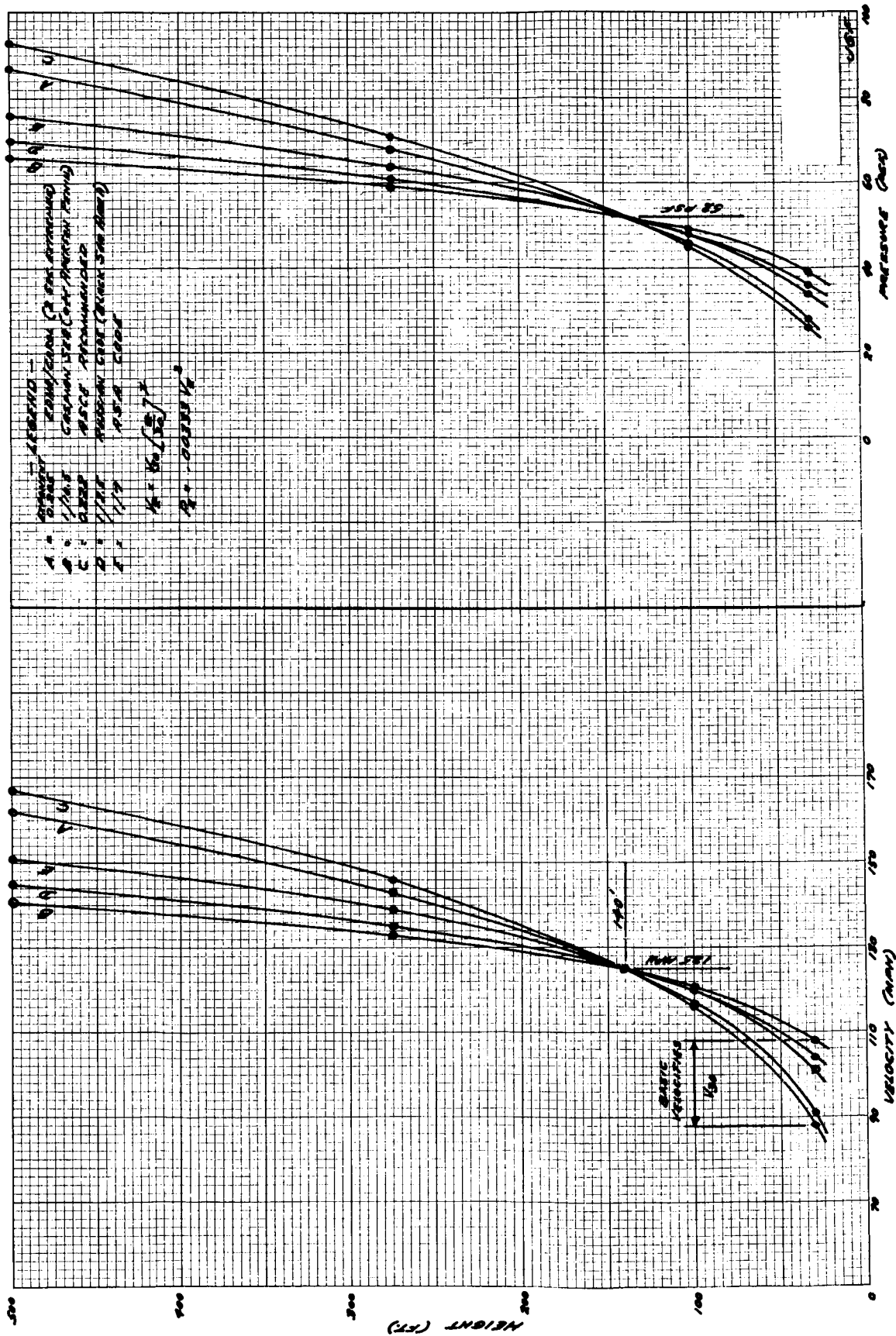


Fig. 8

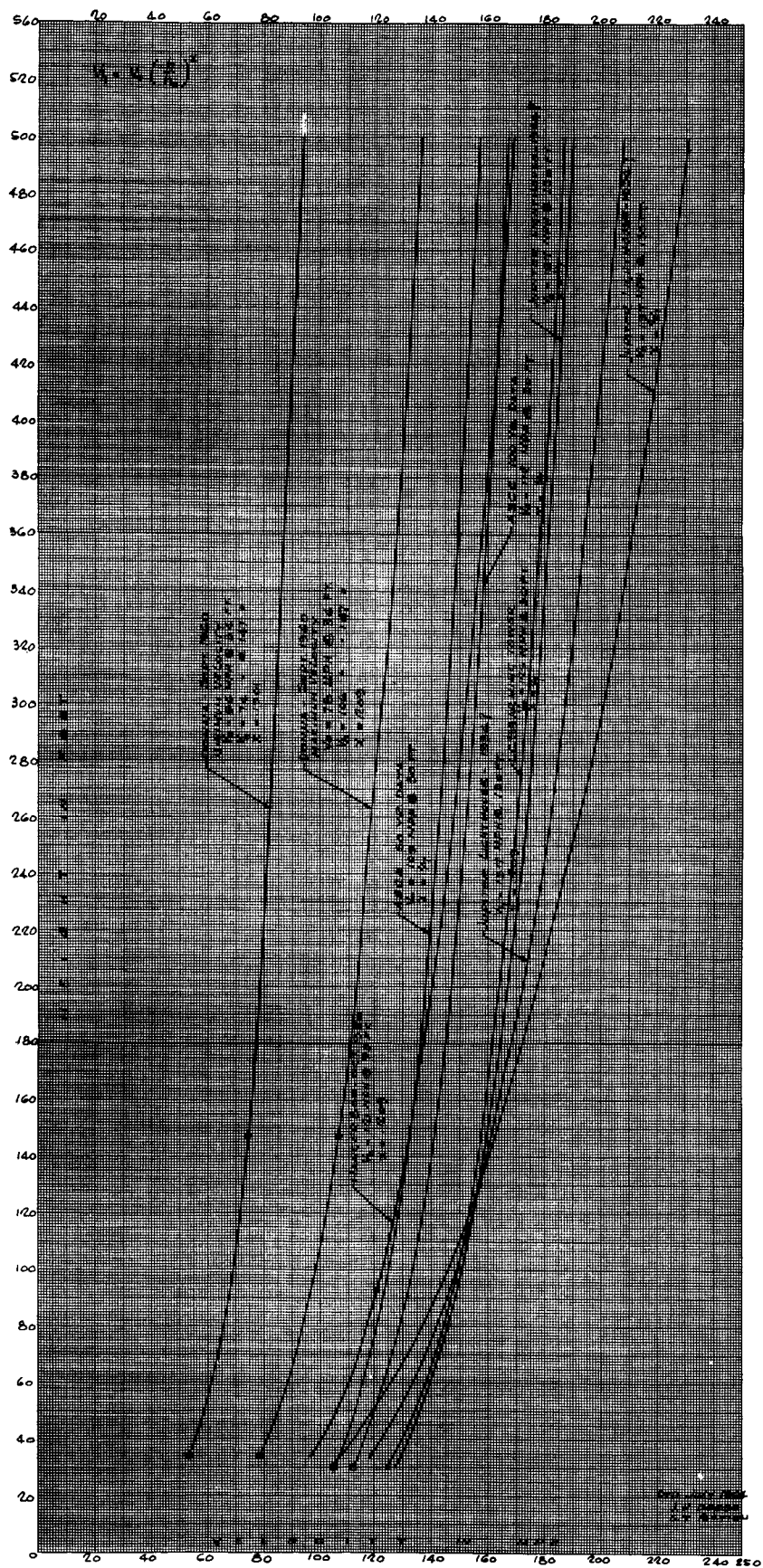


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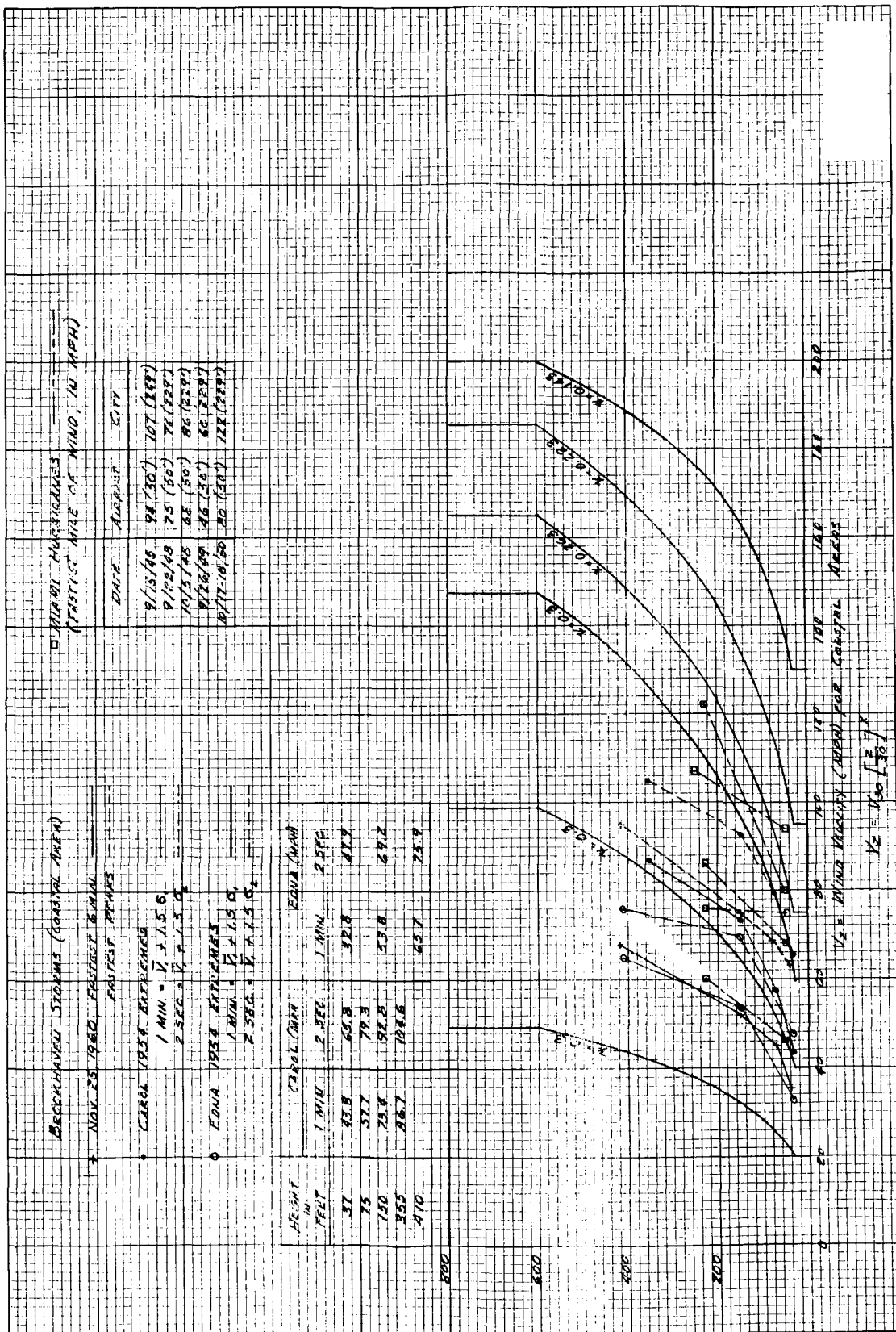


Fig. 10

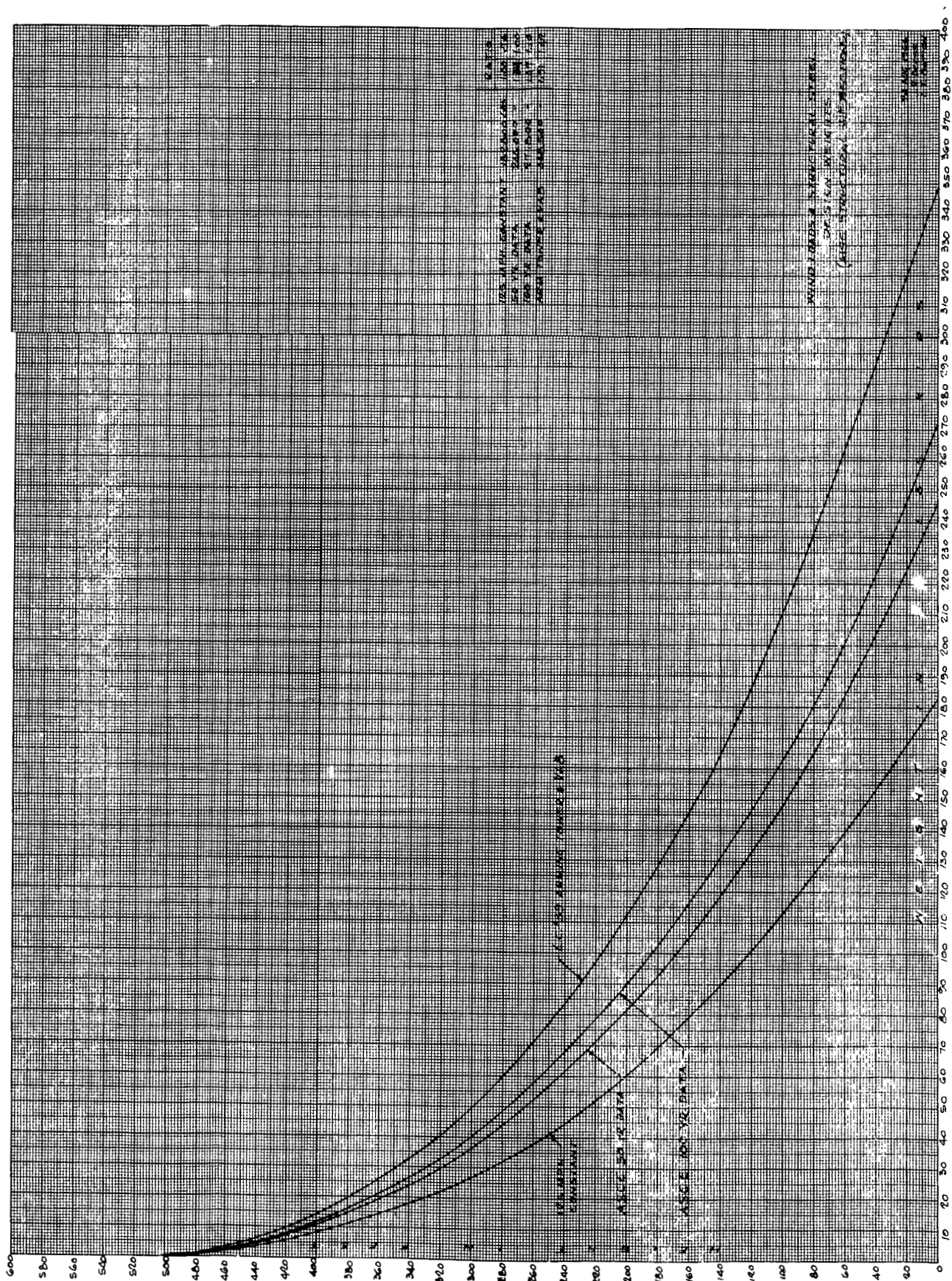
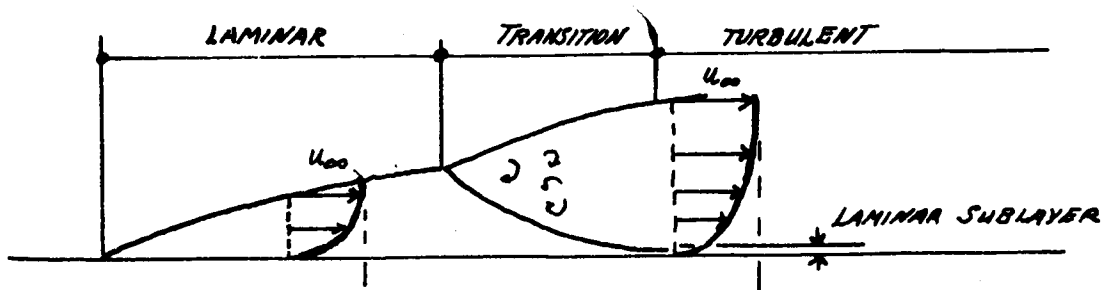
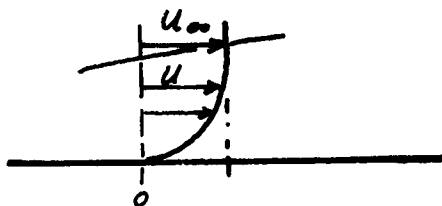


Fig. 12

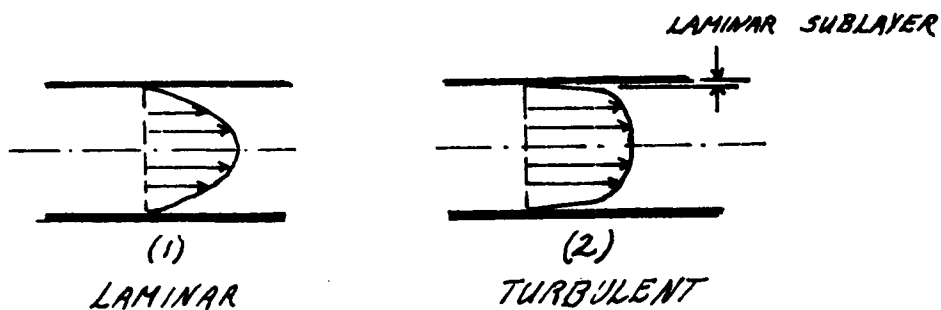


FLOW SCHEME ~ LAMINAR TO TURBULENT



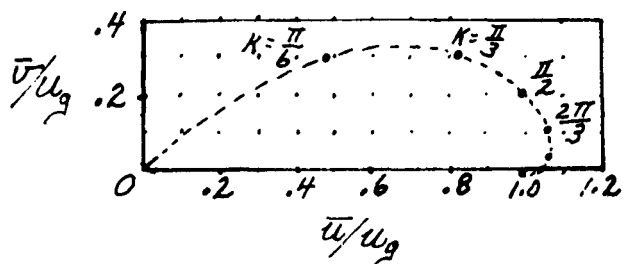
$$\tau = \mu \frac{du}{dy}$$

CONDITIONS FOR LAMINAR FLOW



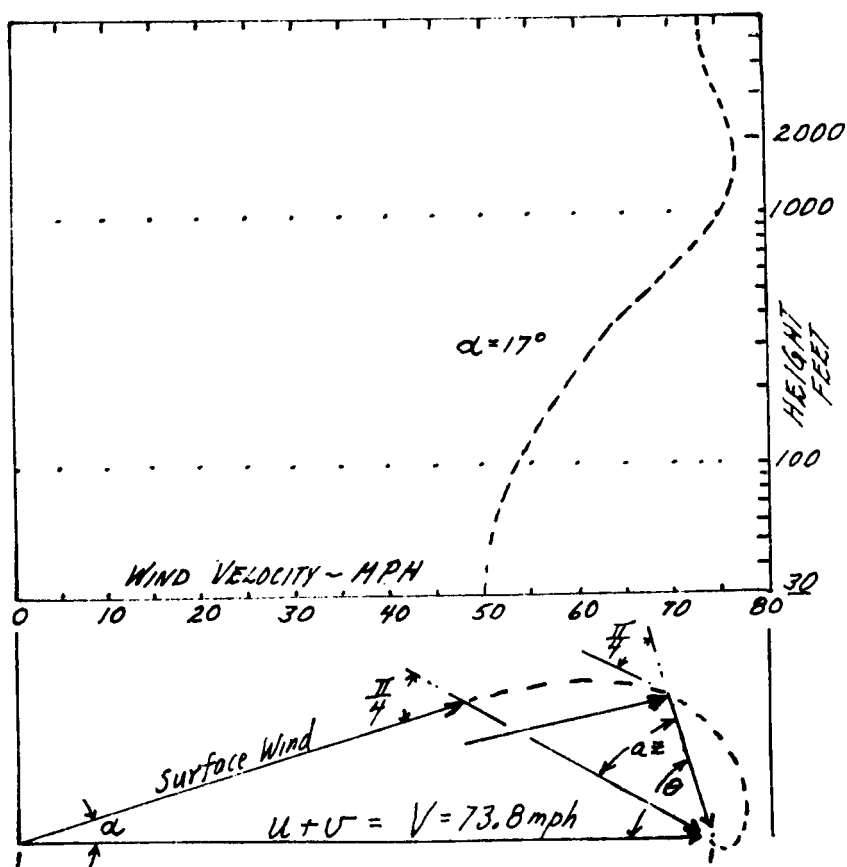
COMPARATIVE PROFILES of VELOCITIES
TUBE FLOW

Fig. 13



$$k = az$$

Ekman Spiral (Normalized)



Ekman Spiral
(Particular Case)

Fig. 14

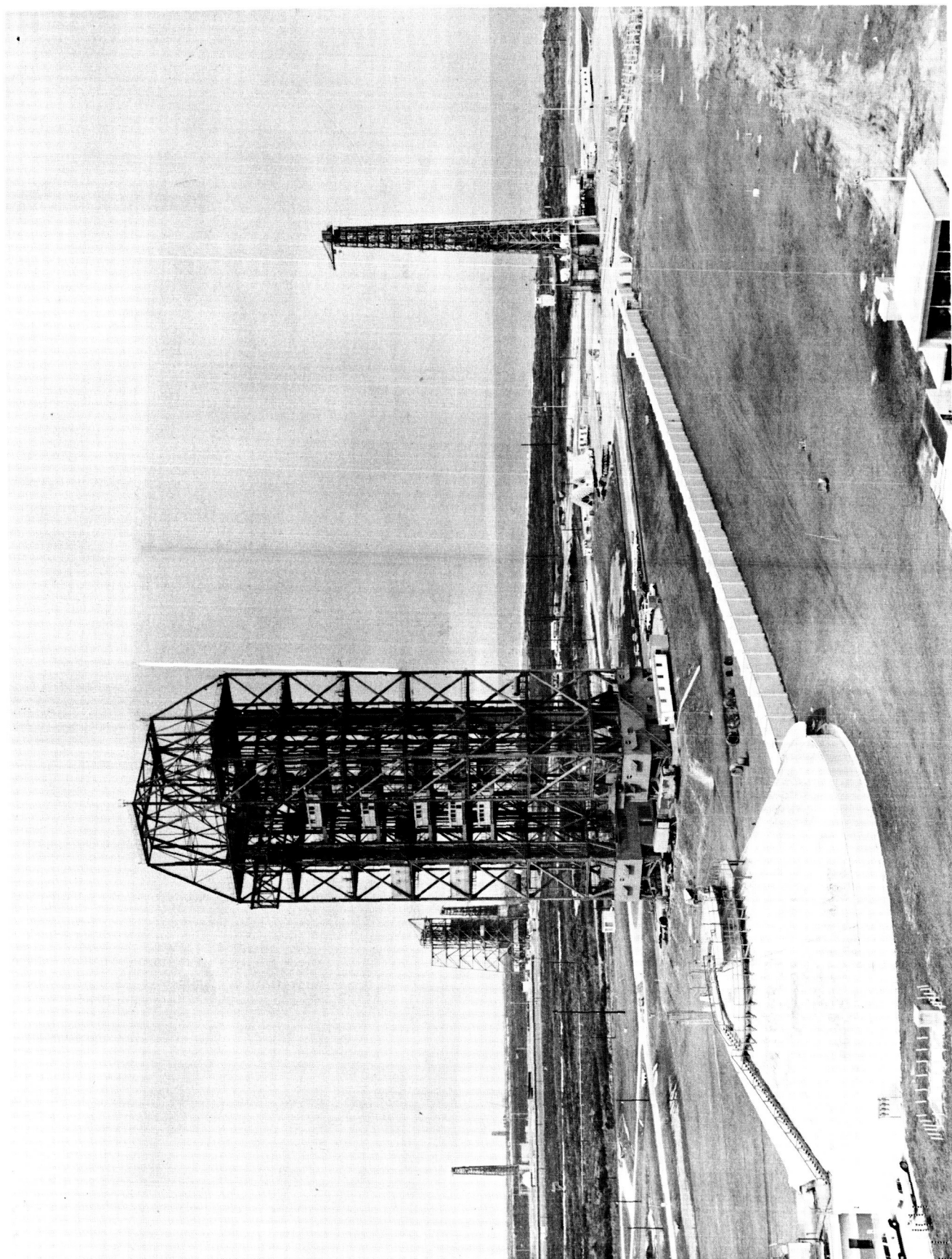


Fig. 15.

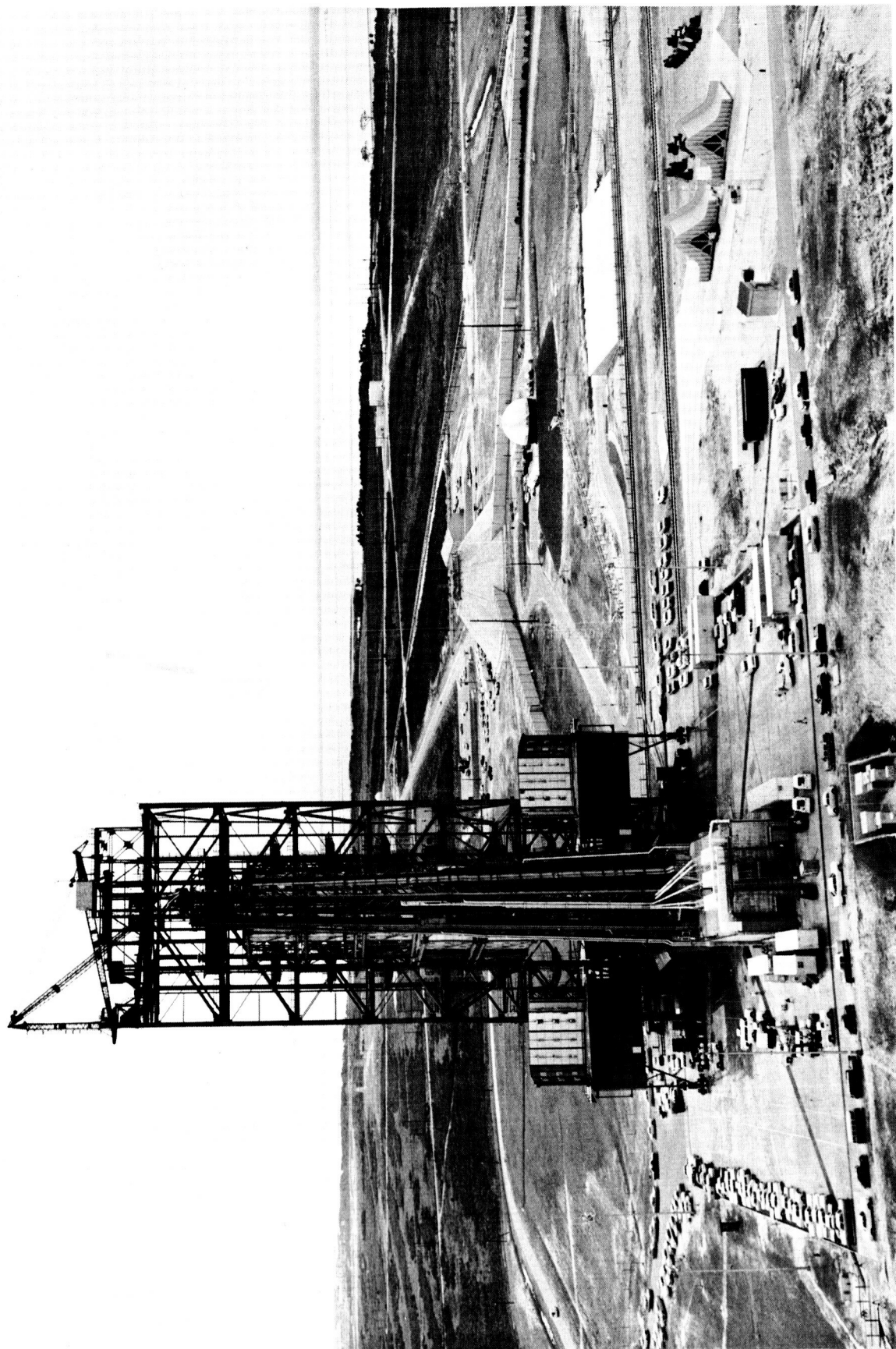


Fig. 16



Fig. 17



Fig. 18



Fig. 19



Fig. 20

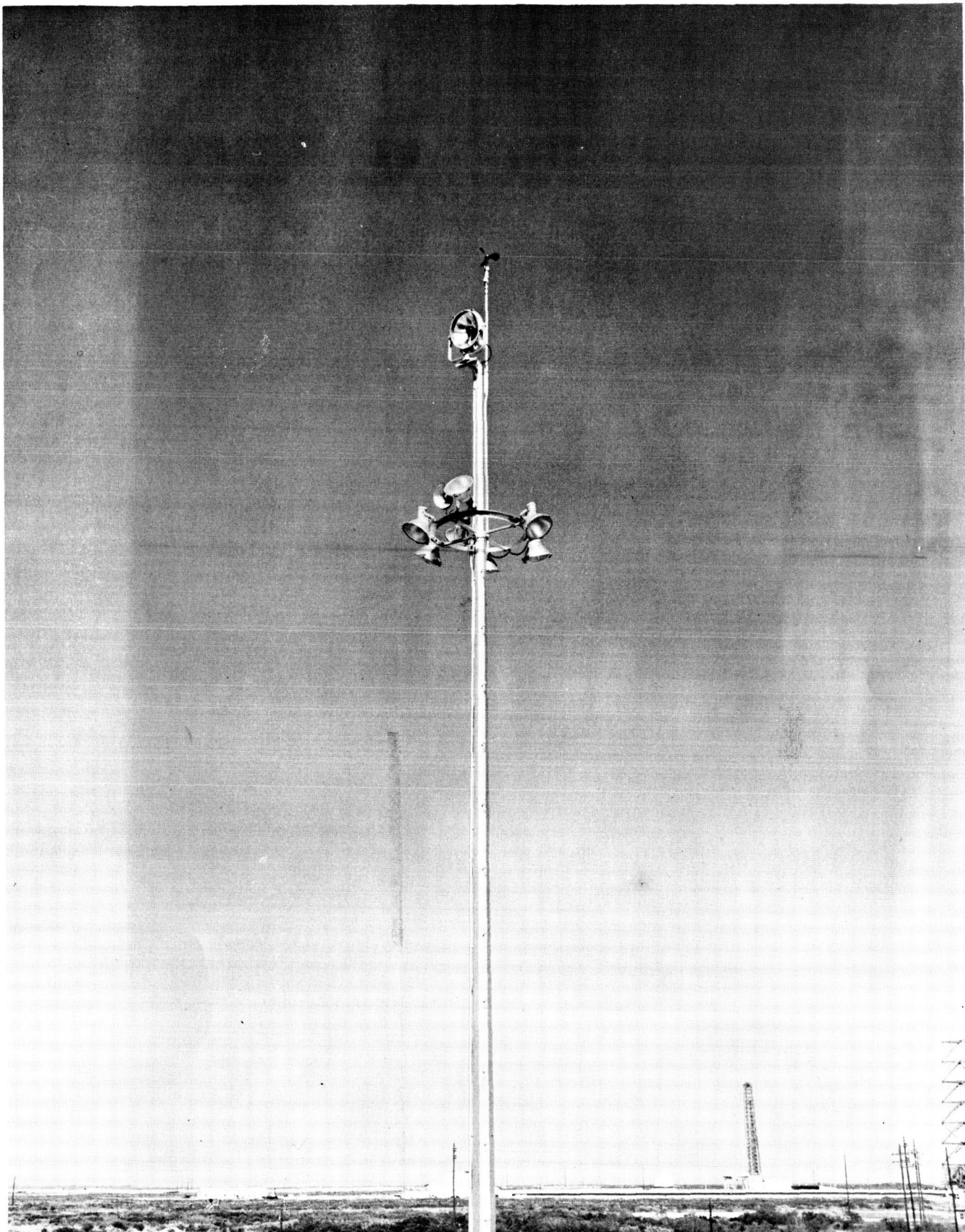
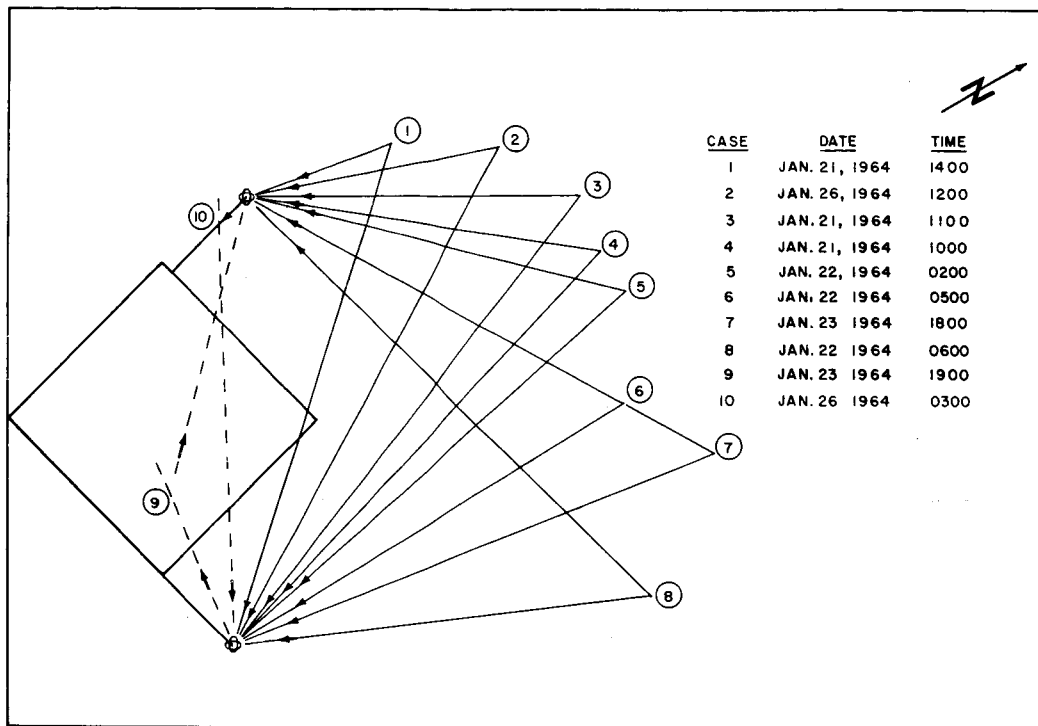


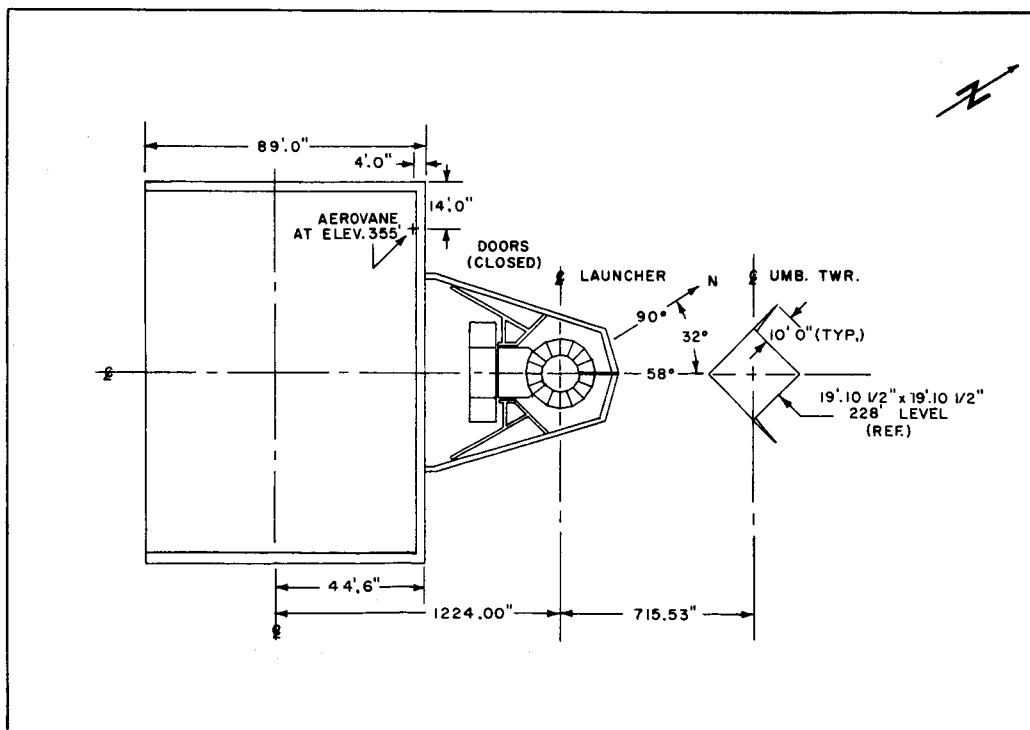
Fig. 21



Fig. 22

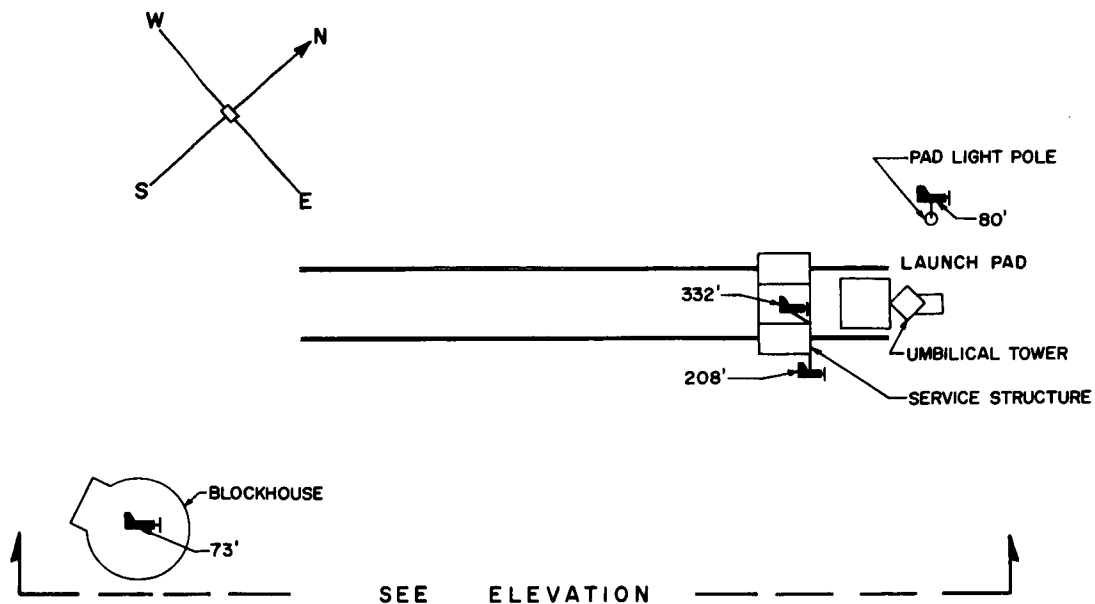


WIND DIRECTIONS MEASURED AT 228-FOOT LEVEL OF UMBILICAL TOWER



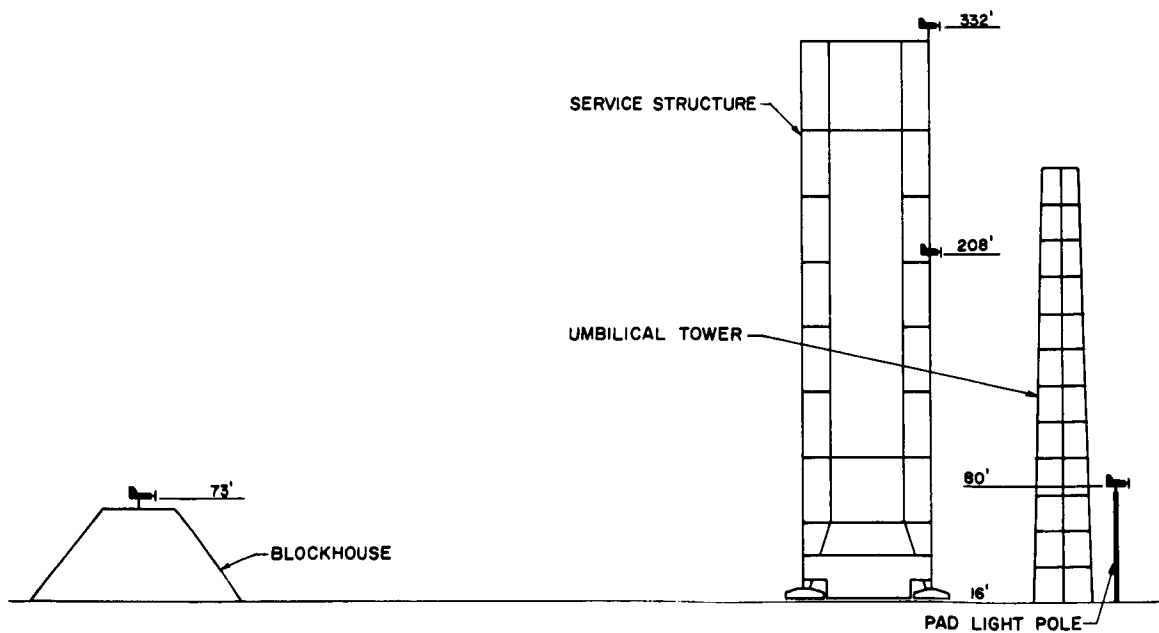
SERVICE STRUCTURE, PAD 37B (236-Foot Level)

Fig. 23



PLAN
COMPLEX 34 AEROVANE LOCATION

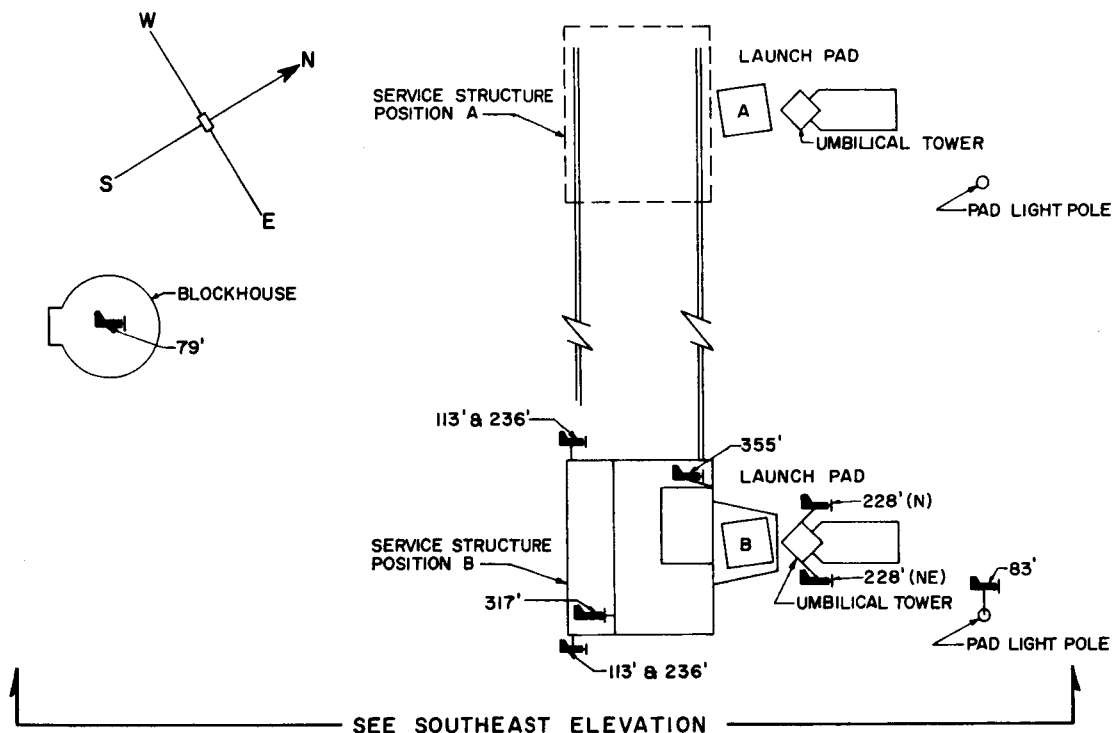
PREPARED BY DOW / W.B.W. / L.A.



SOUTHEAST ELEVATION
COMPLEX 34 AEROVANE LOCATION

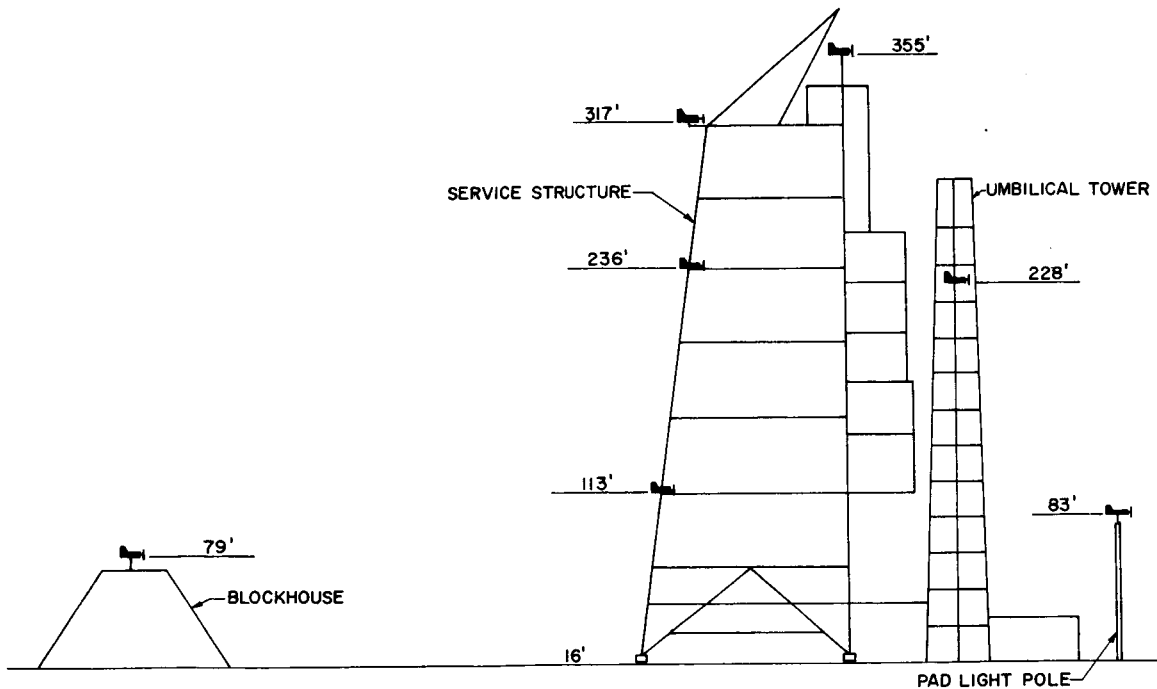
PREPARED BY DOW / W.B.W. / L.A.

Fig. 24



PLAN
COMPLEX 37 AEROVANE LOCATION

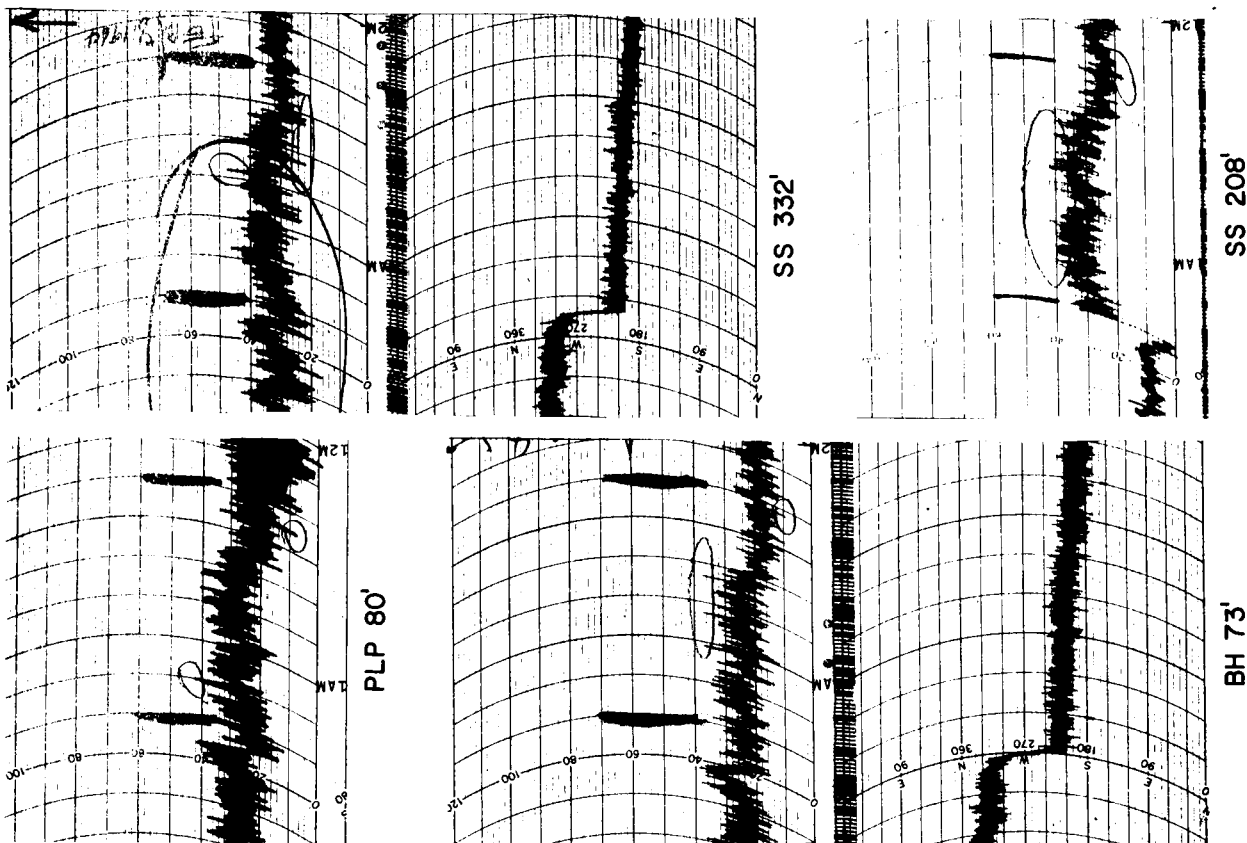
PREPARED BY DOW/W.B.W./L.A.



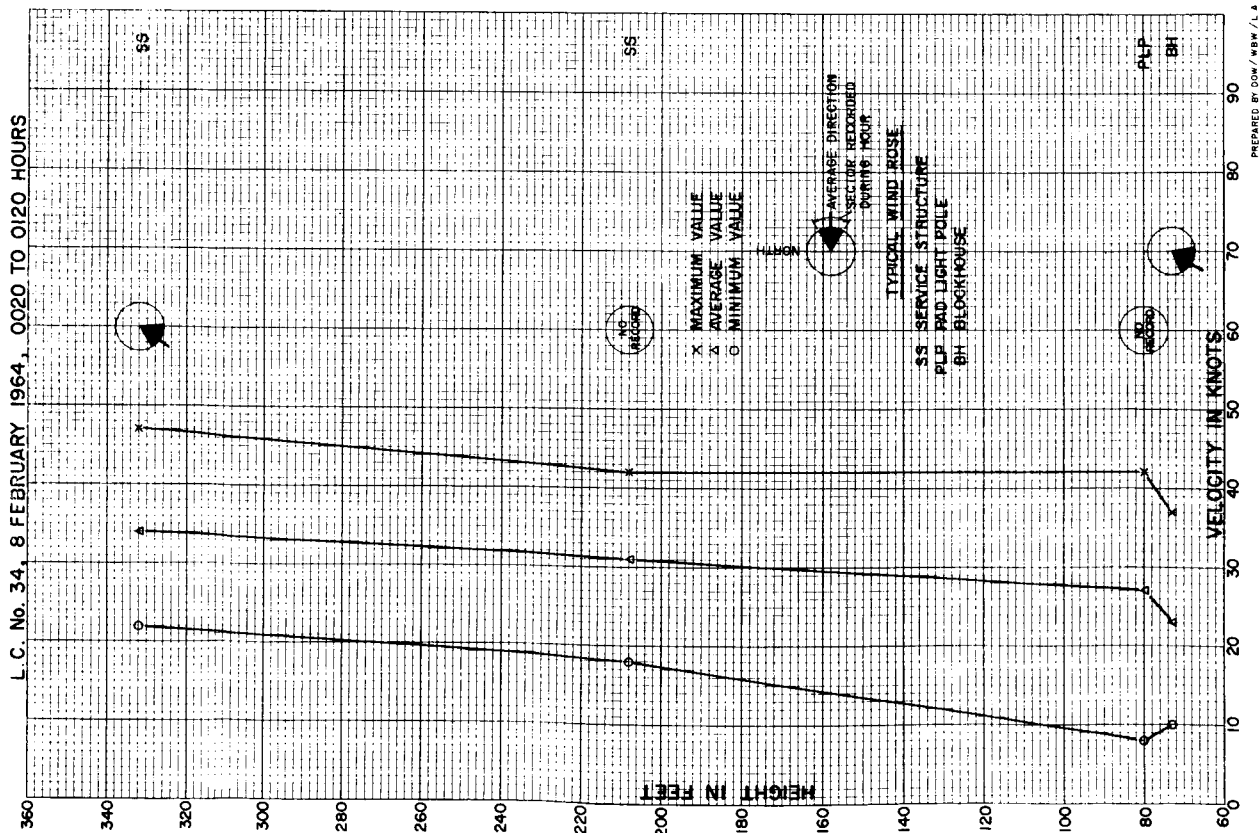
SOUTHEAST ELEVATION
COMPLEX 37 AEROVANE LOCATION

Fig. 25

PREPARED BY DOW/W.B.W./L.A.



PREPARED BY DOW / MBW / ENP



PREPARED BY DOW / MBW / L.A

Fig. 26

L.C. No. 37, 8 FEBRUARY 1964, 0030 TO 0130 HOURS

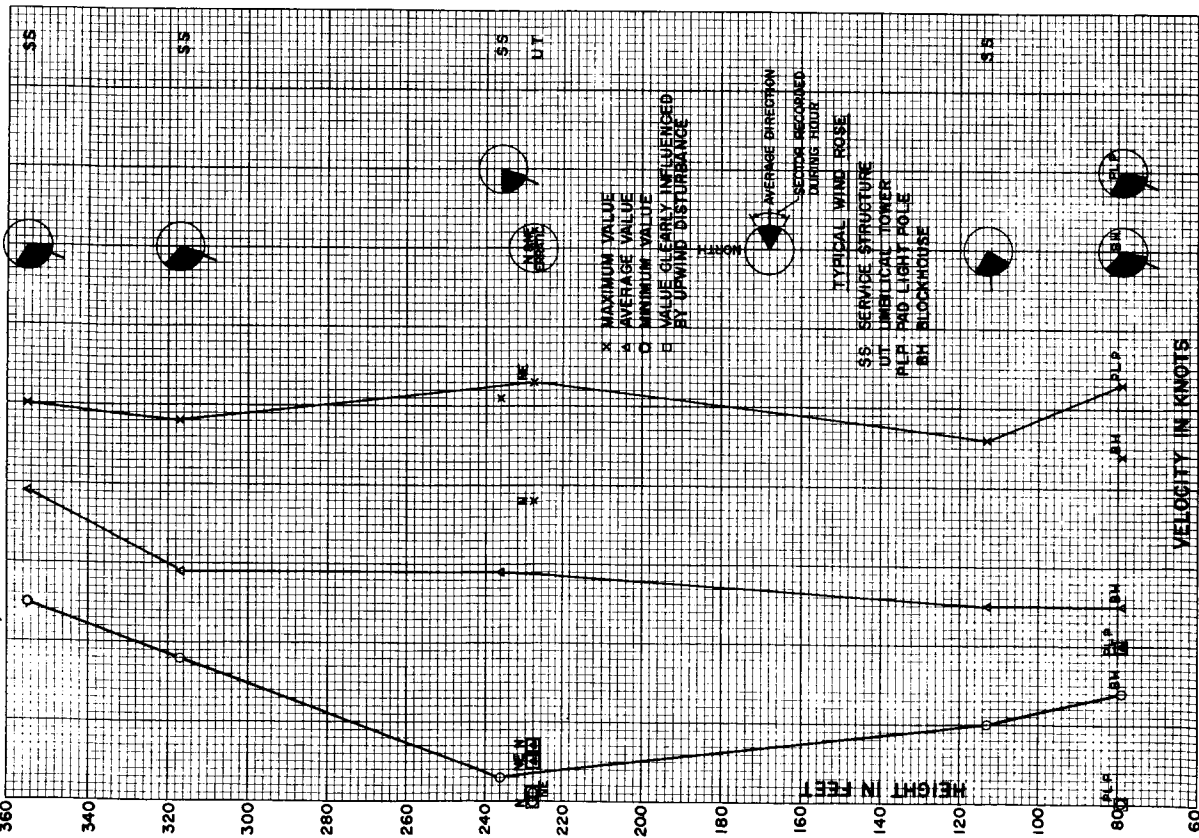
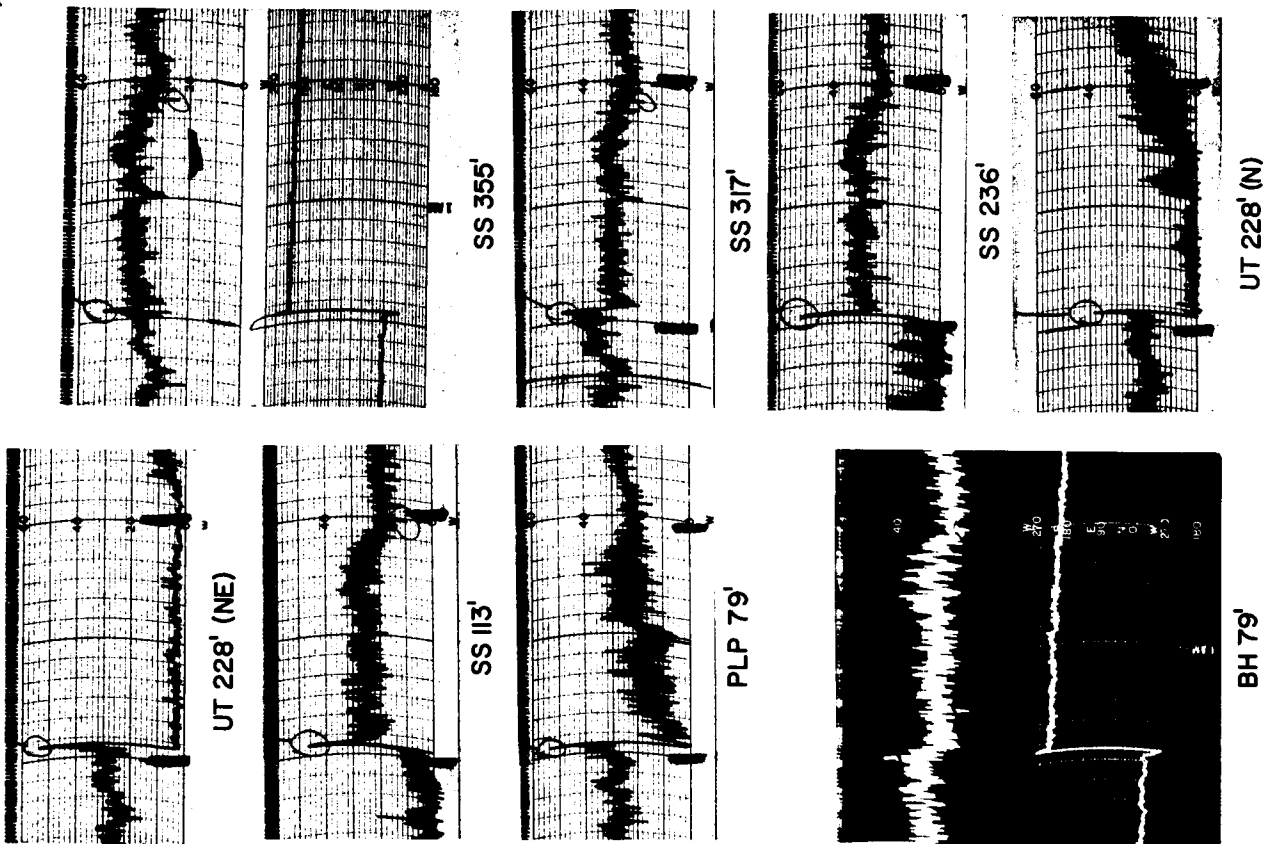


Fig. 27



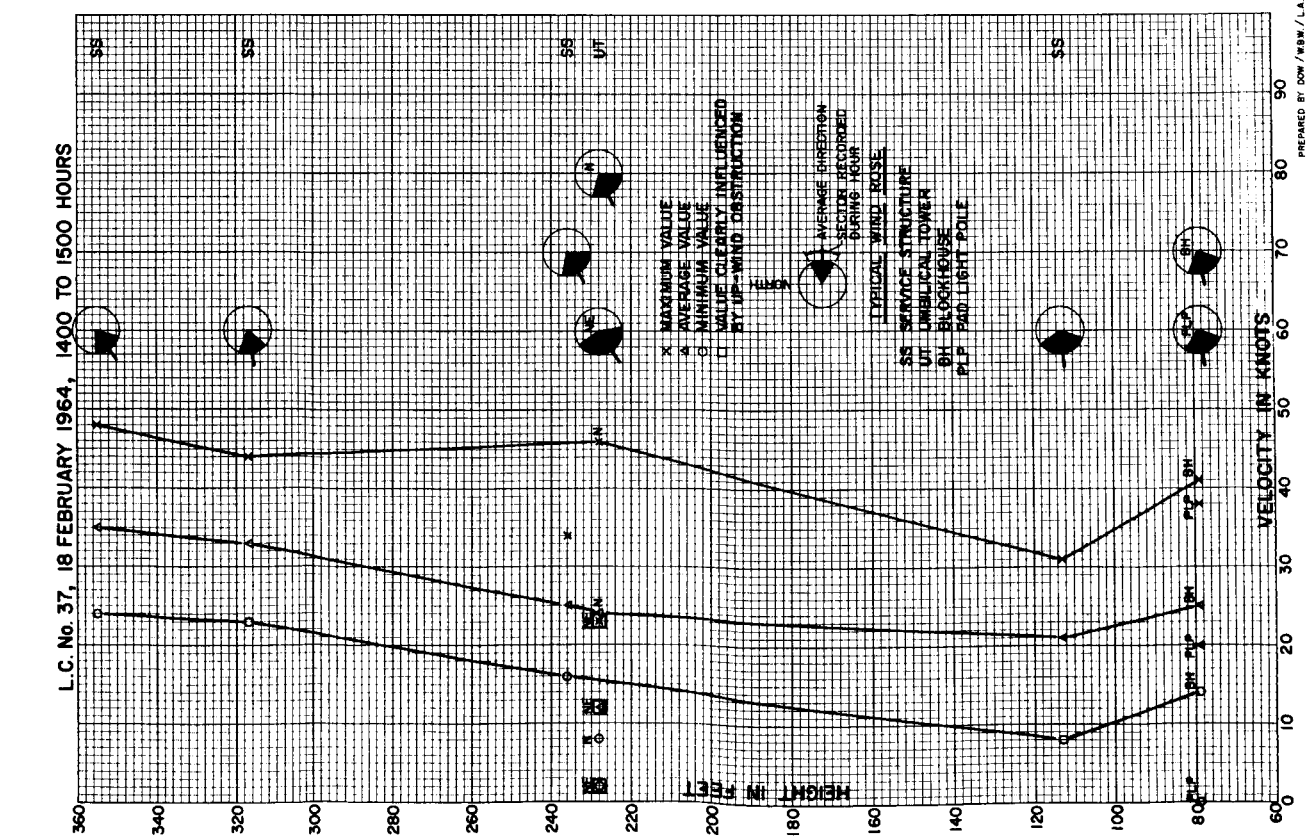
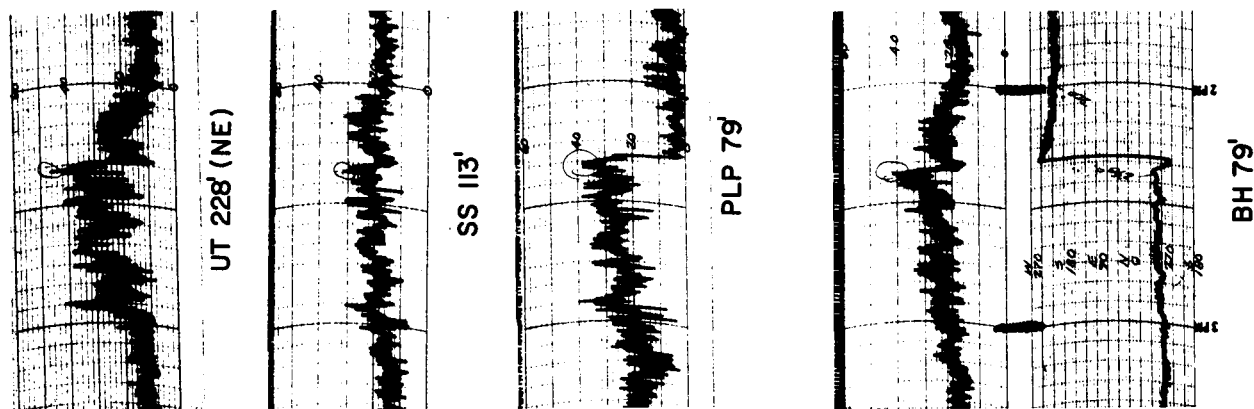


Fig. 28



PREPARED BY DOW / MBW / E.N.P.

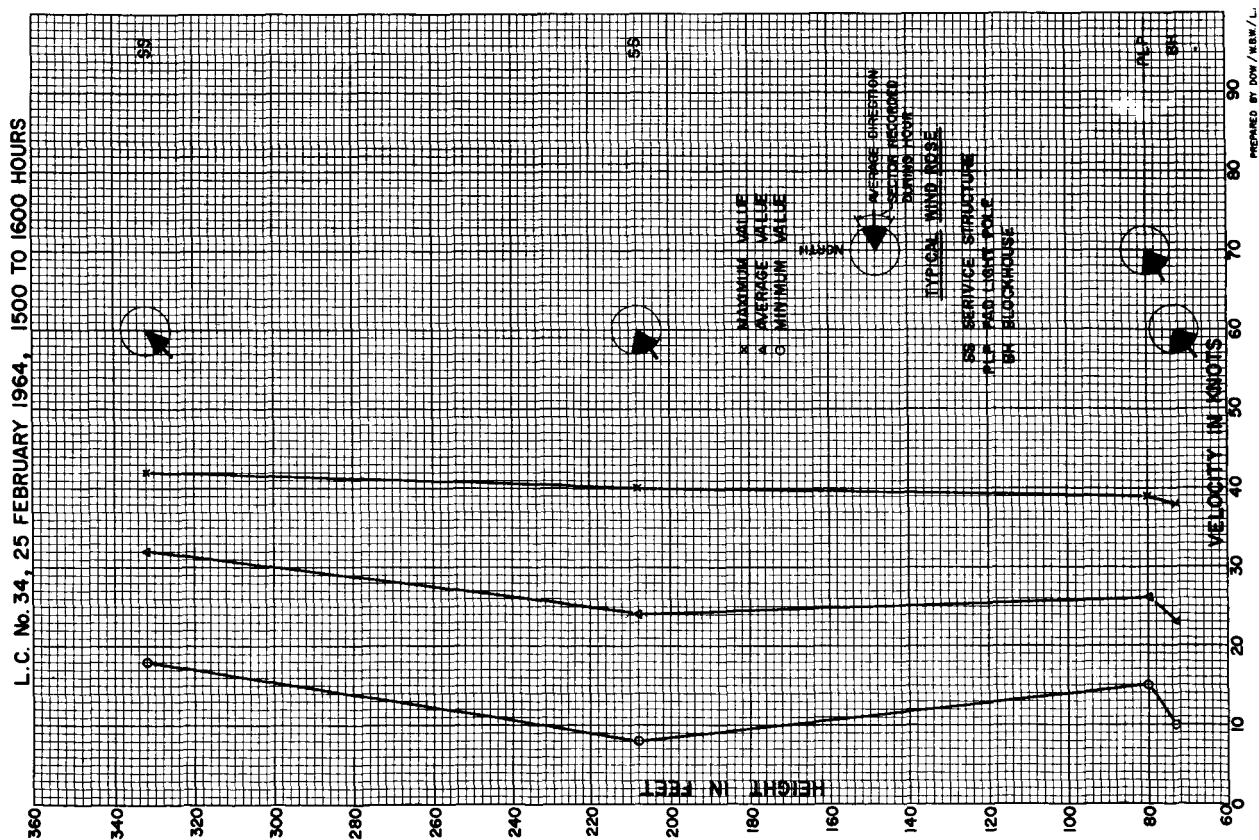
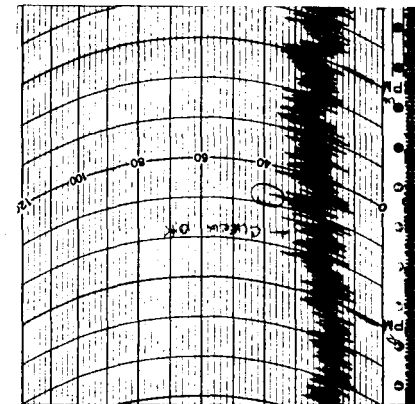
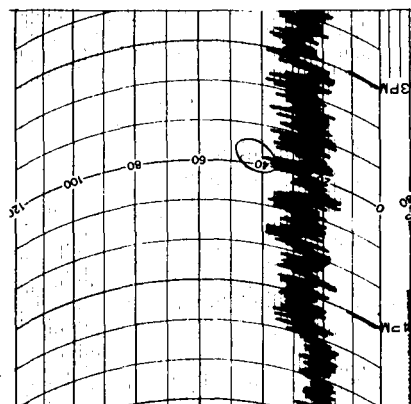
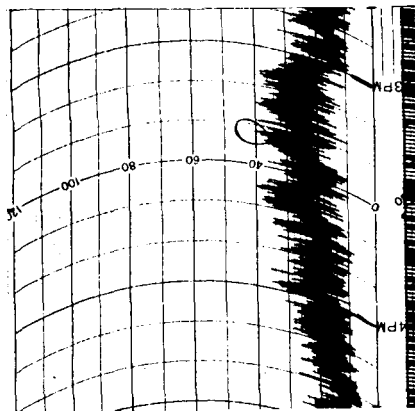
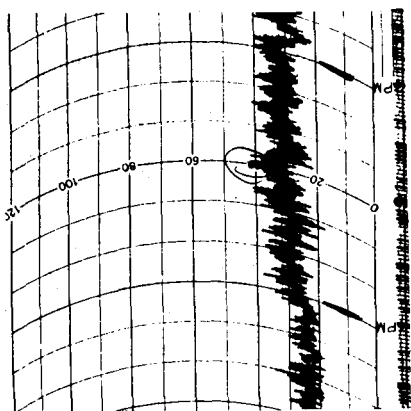


Fig. 29

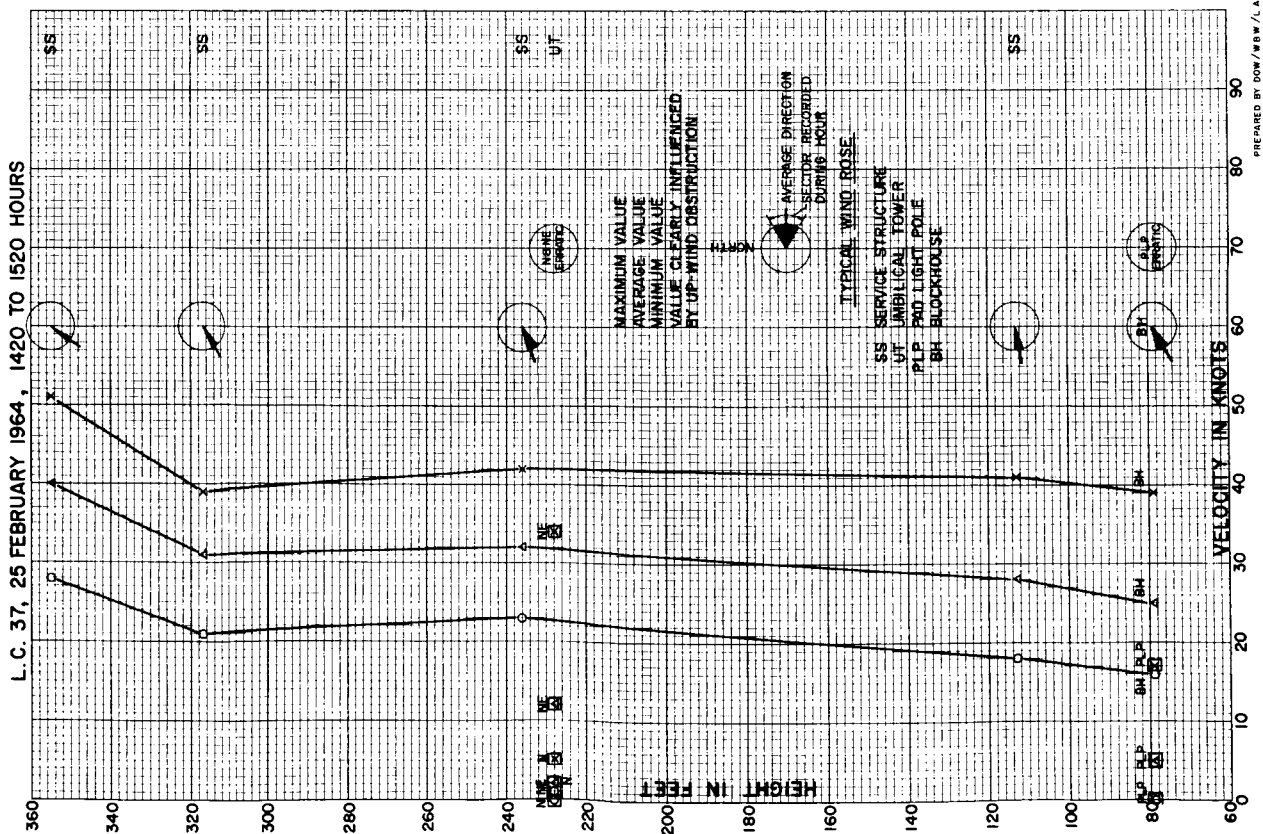
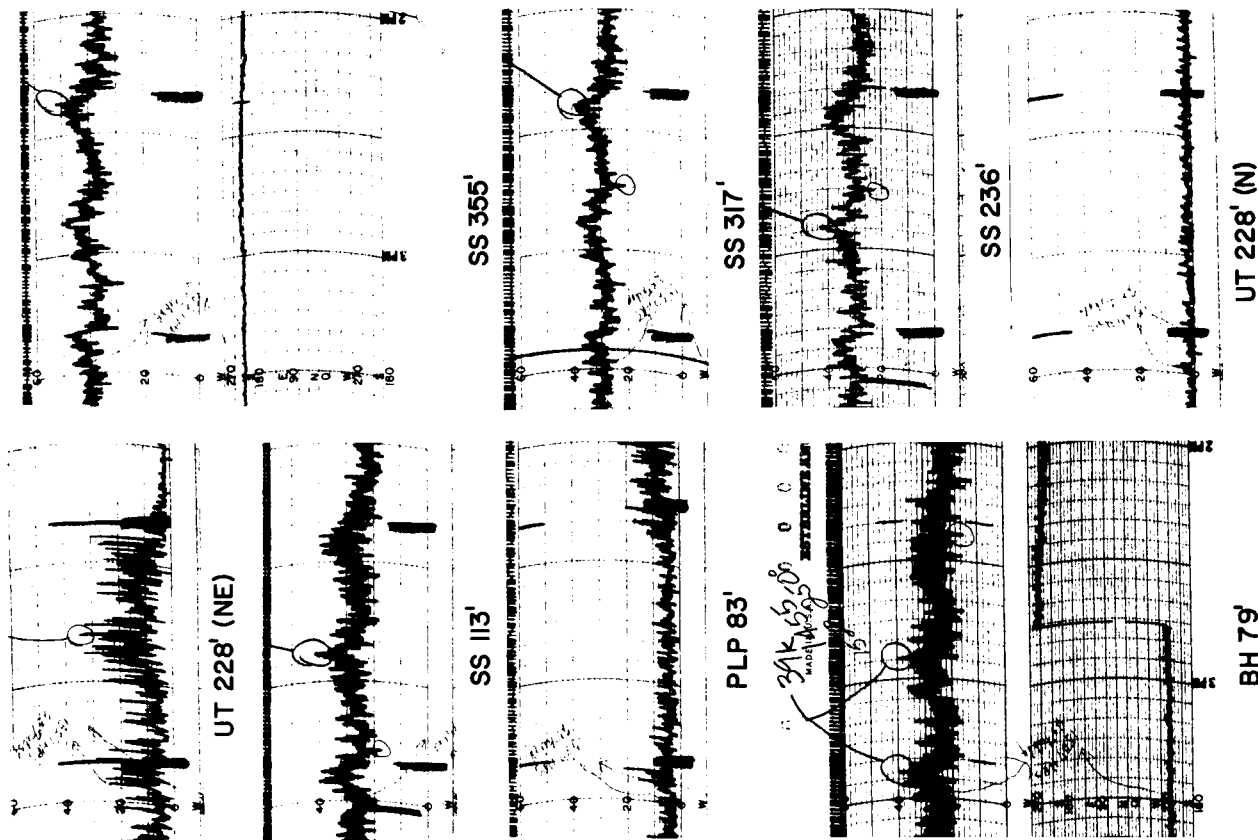
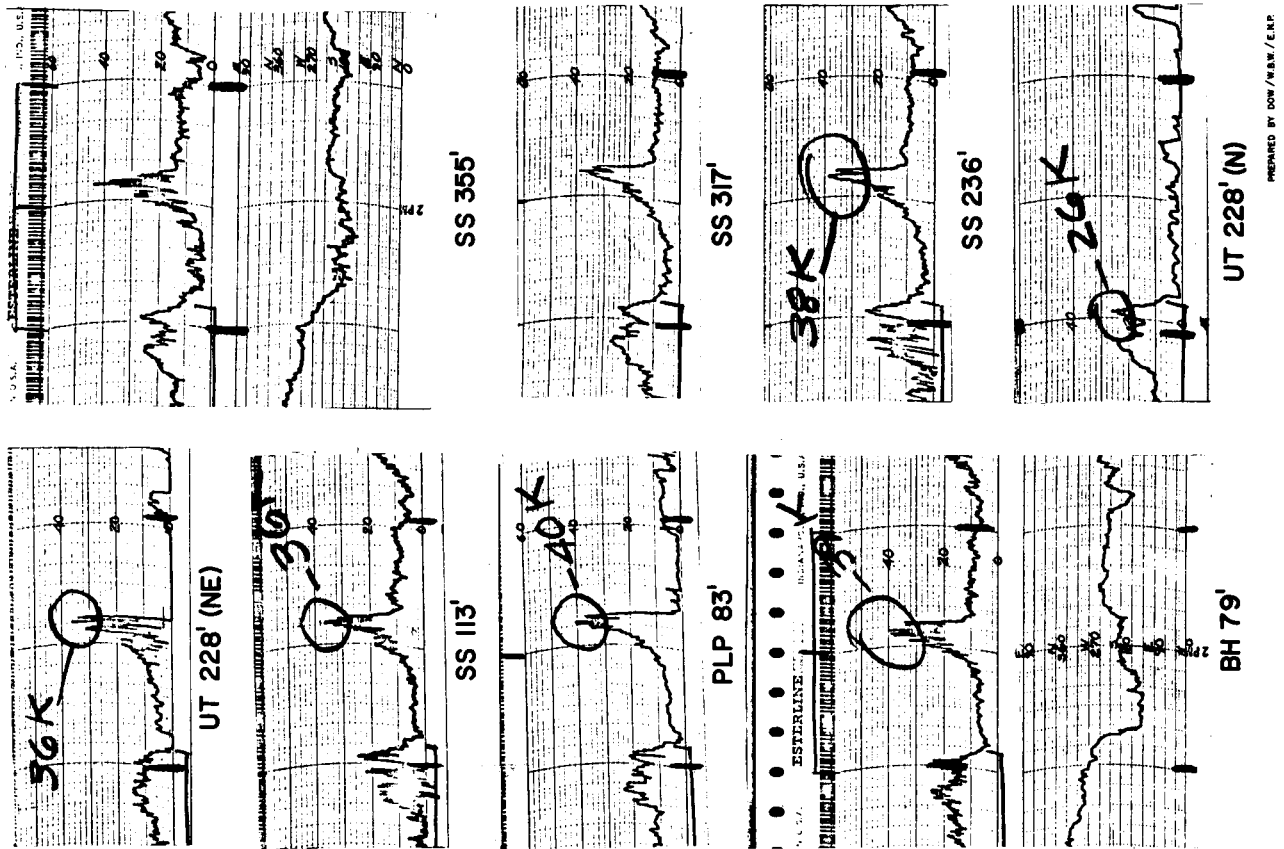
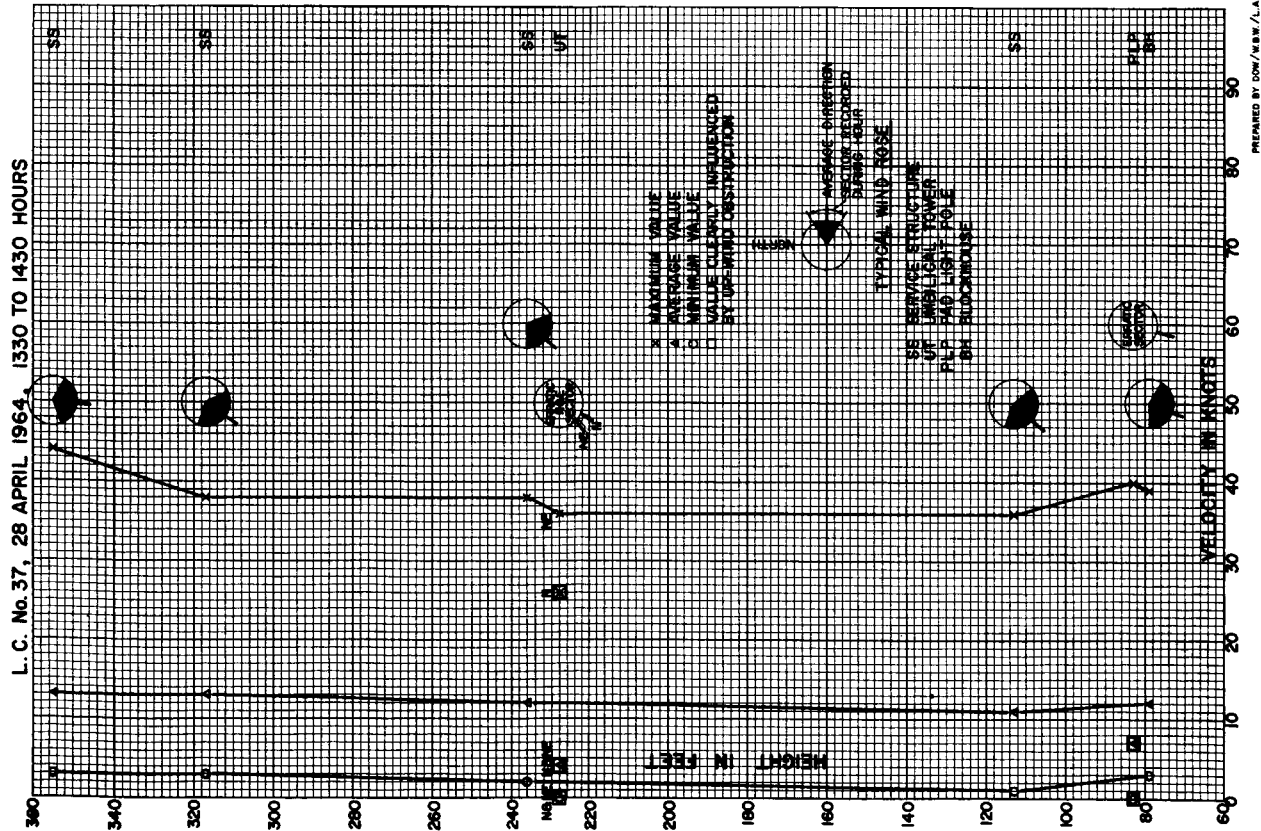


Fig. 30





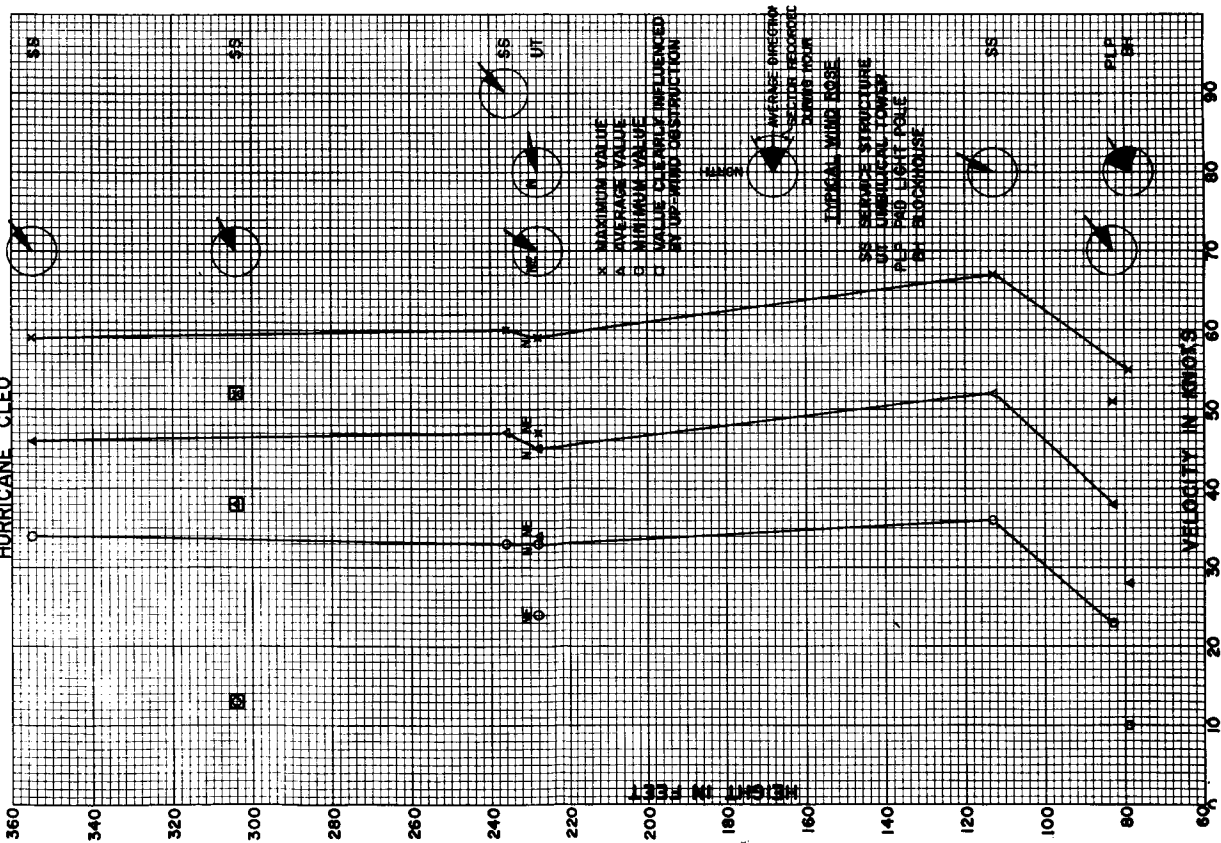
PREPARED BY DOW/NEW/ENP



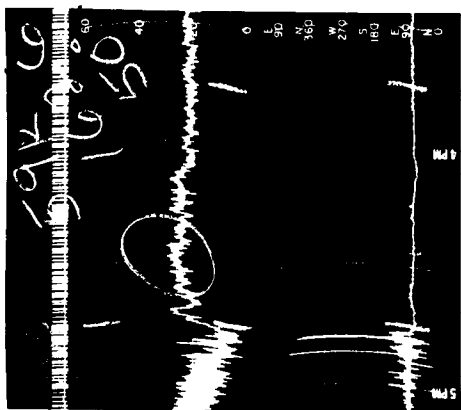
PREPARED BY DOW/NEW/L.A.

Fig. 31

L.C. No. 37, 27 AUGUST 1964, 1545 TO 1645 HOURS
HURRICANE CLEO



PREPARED BY DOW/WBN/ENP



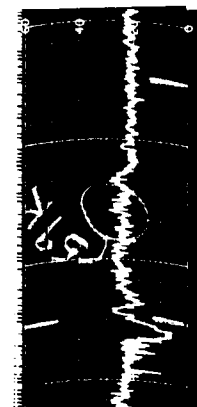
SS 355'



SS 304'



SS 236'



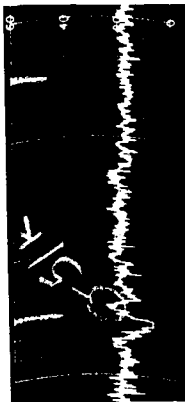
UT 228' (N)



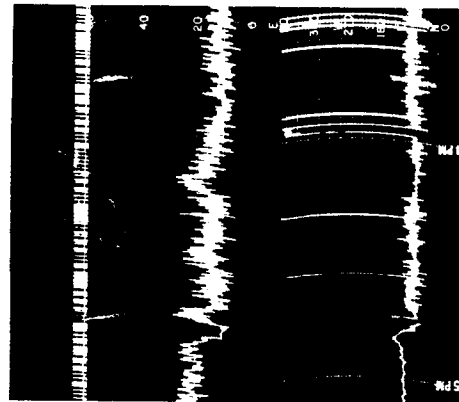
UT 228' (NE)



SS 113'



PLP 83'



BH 79'

Fig. 33

L. C. No. 34, 9 SEPTEMBER 1964, 1400 TO 1500 HOURS
HURRICANE DORA

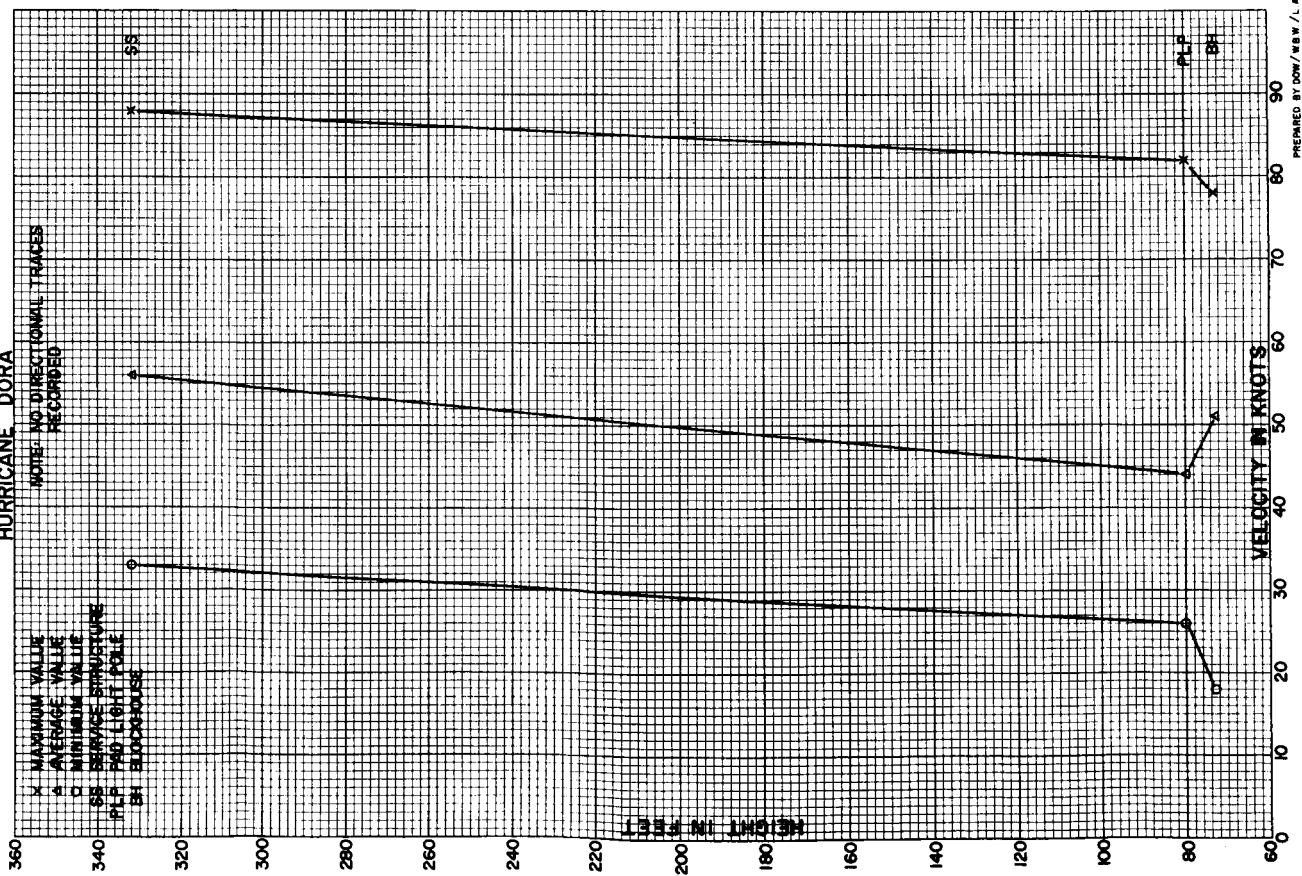
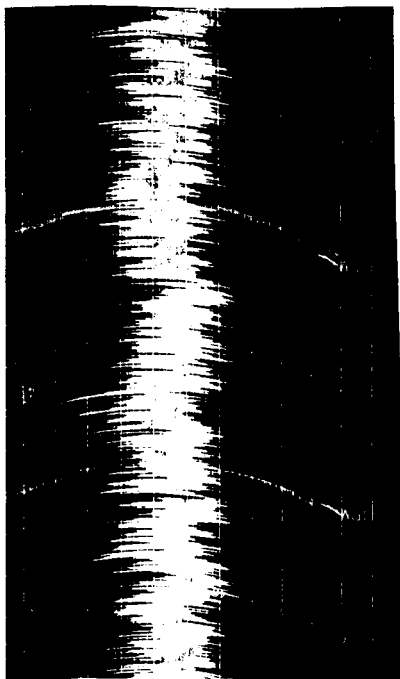
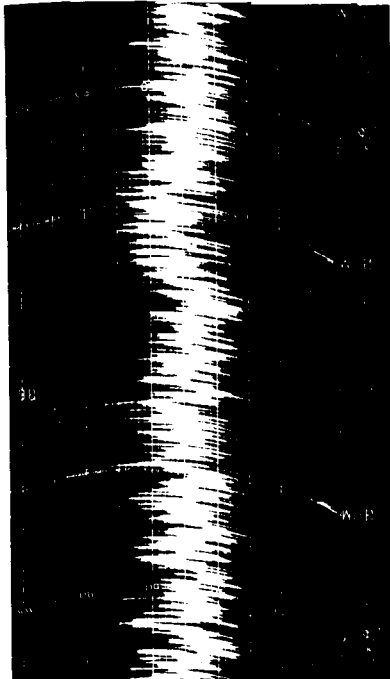


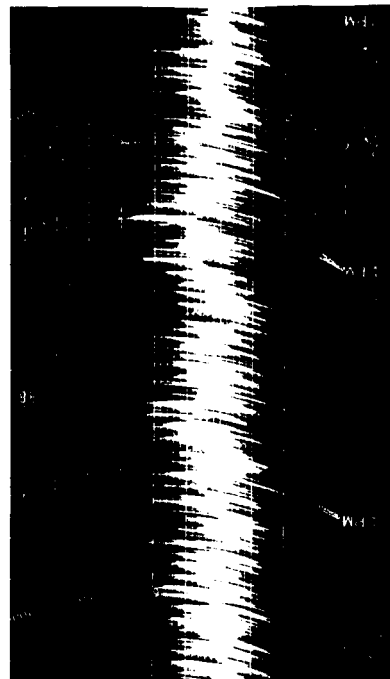
Fig. 34



SS 332'



PLP 80'



BH 73'

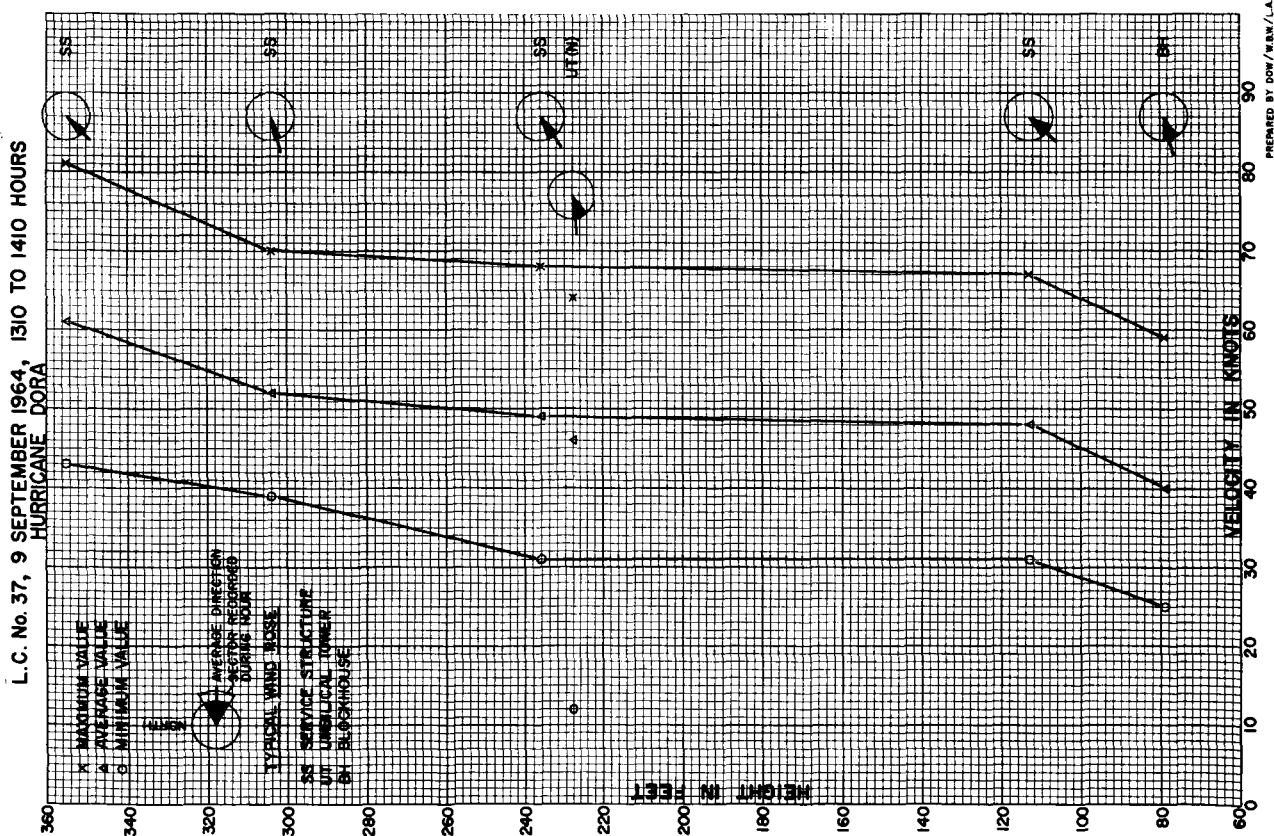
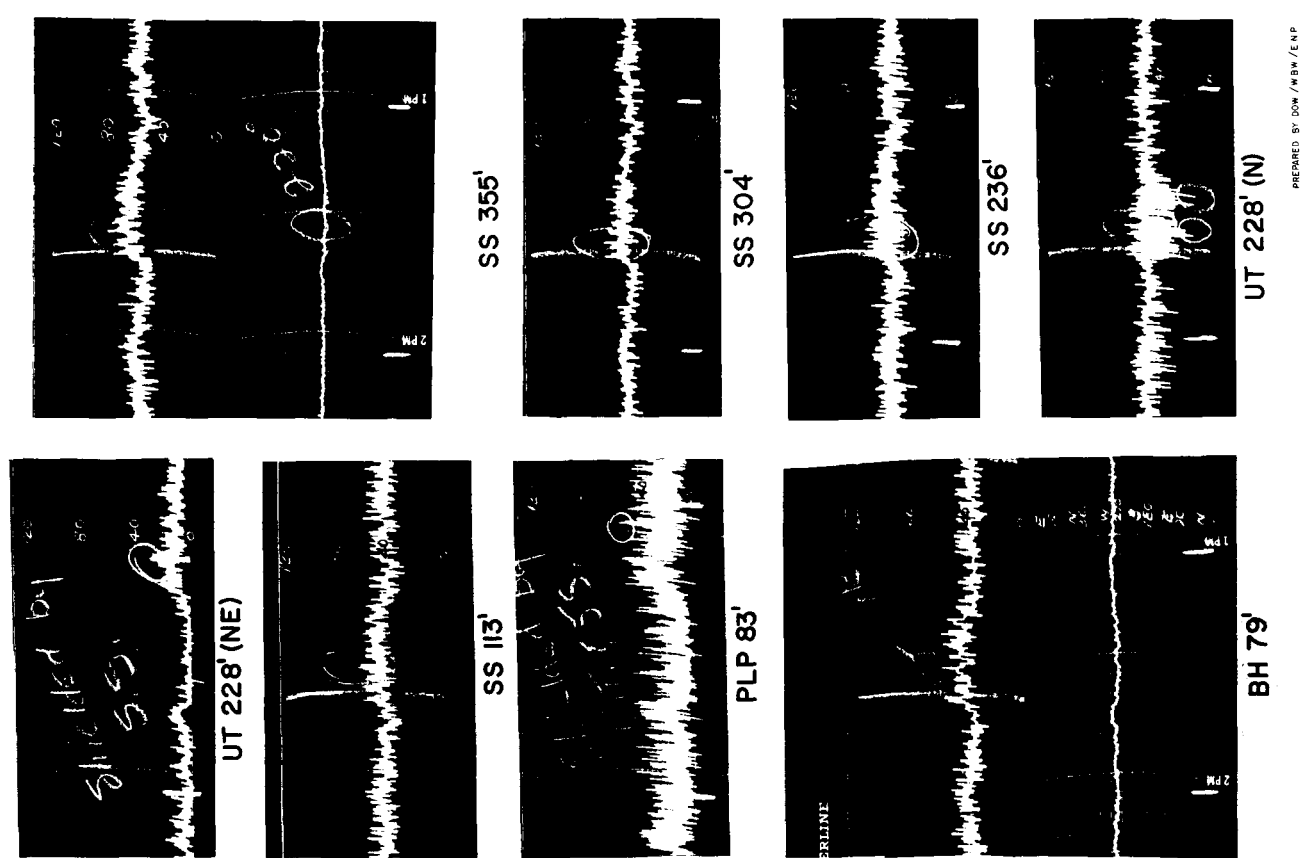


Fig. 35

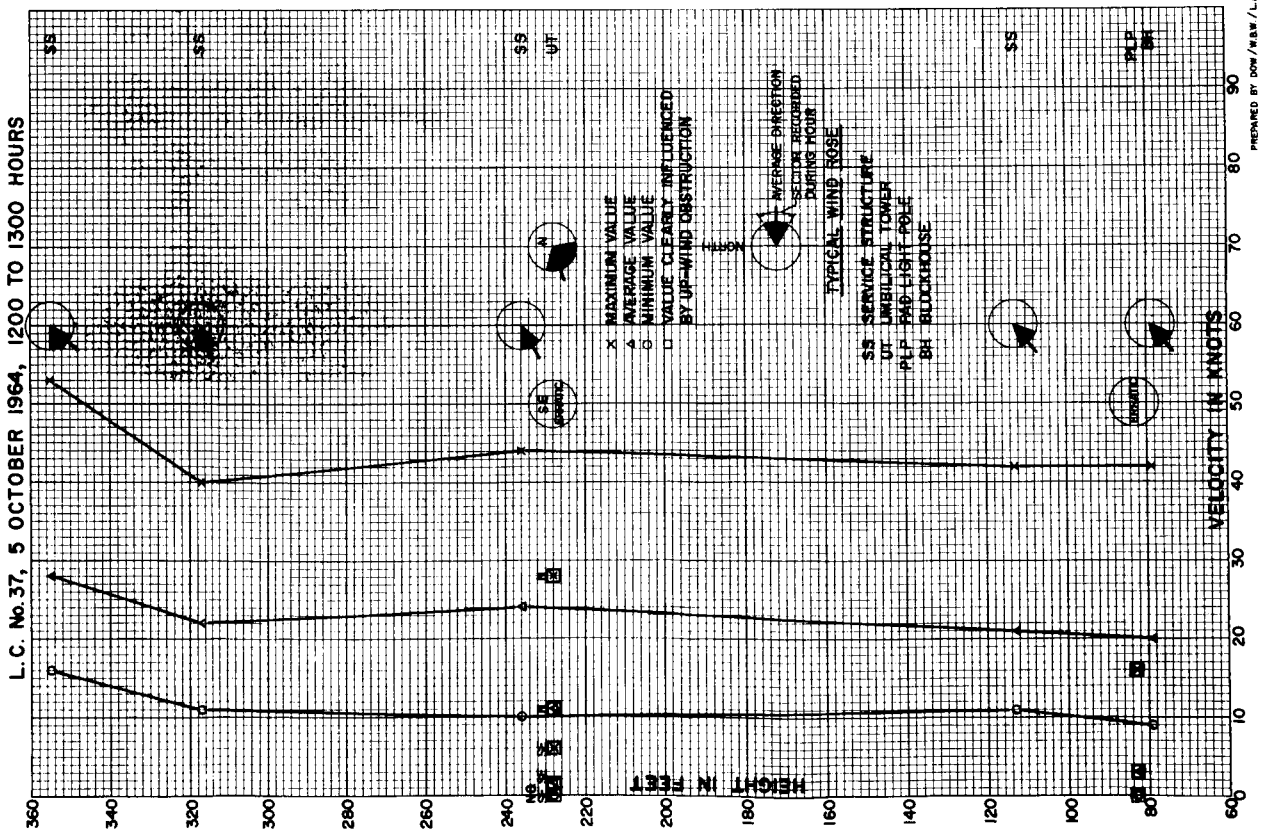
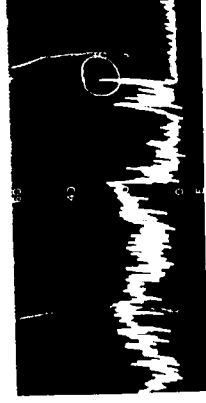
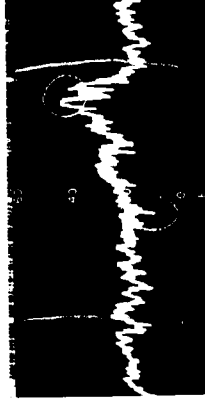
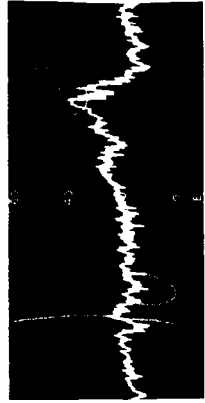
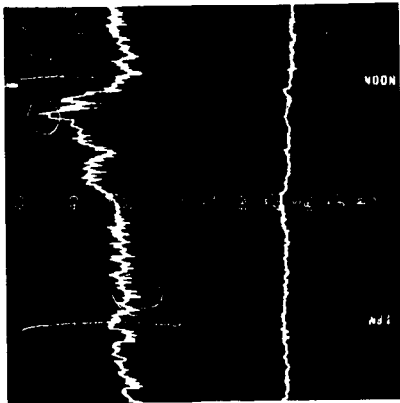
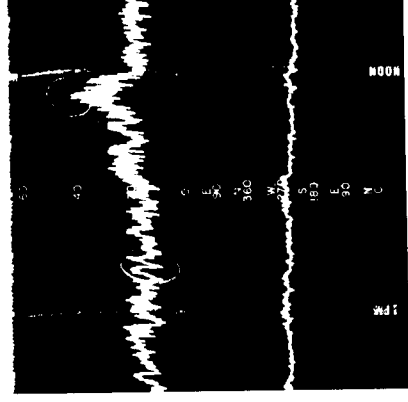
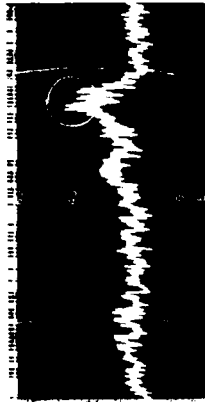
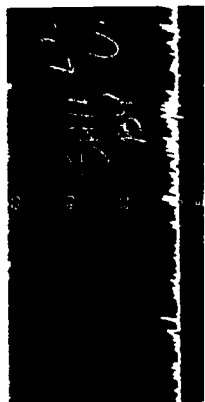


Fig. 36



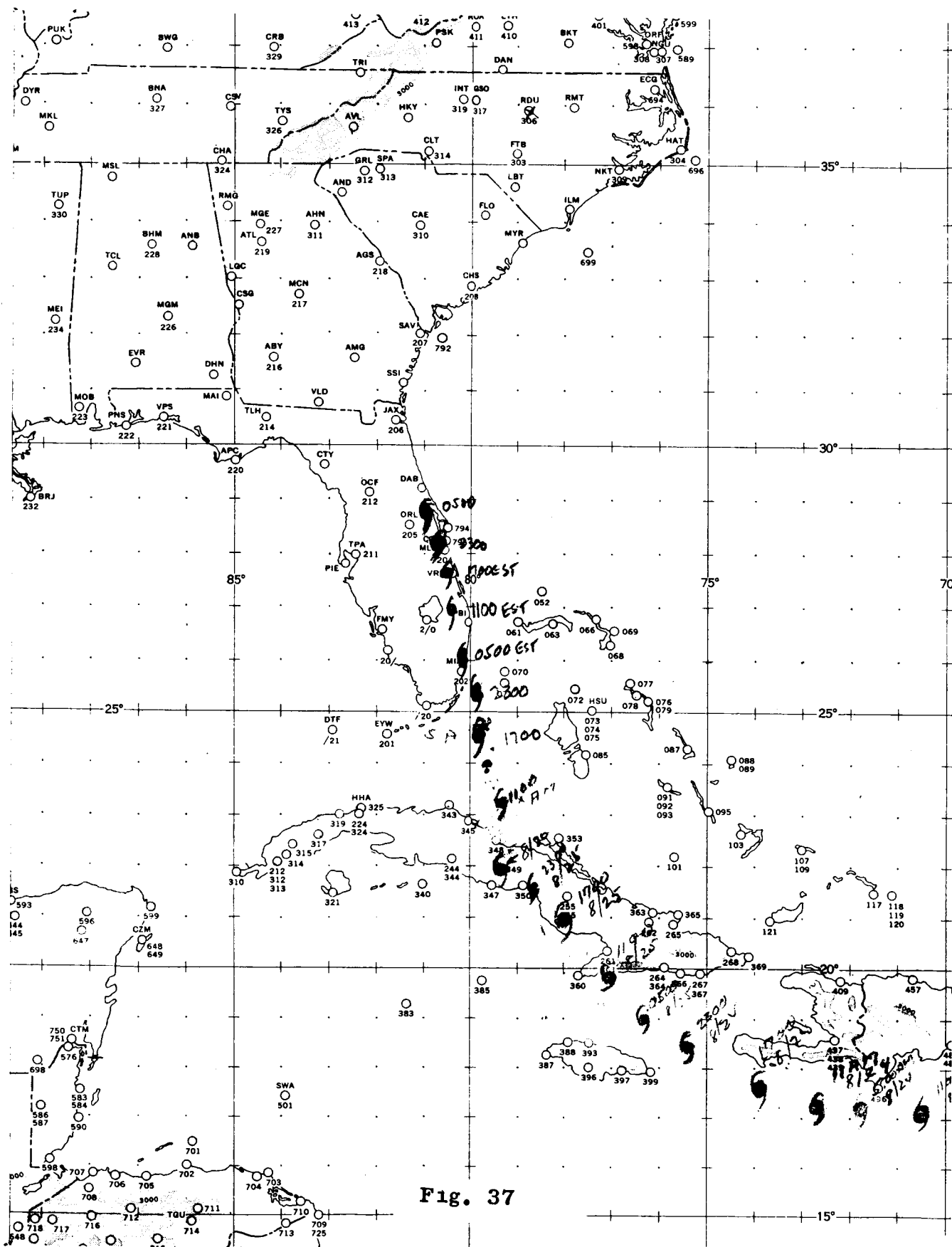
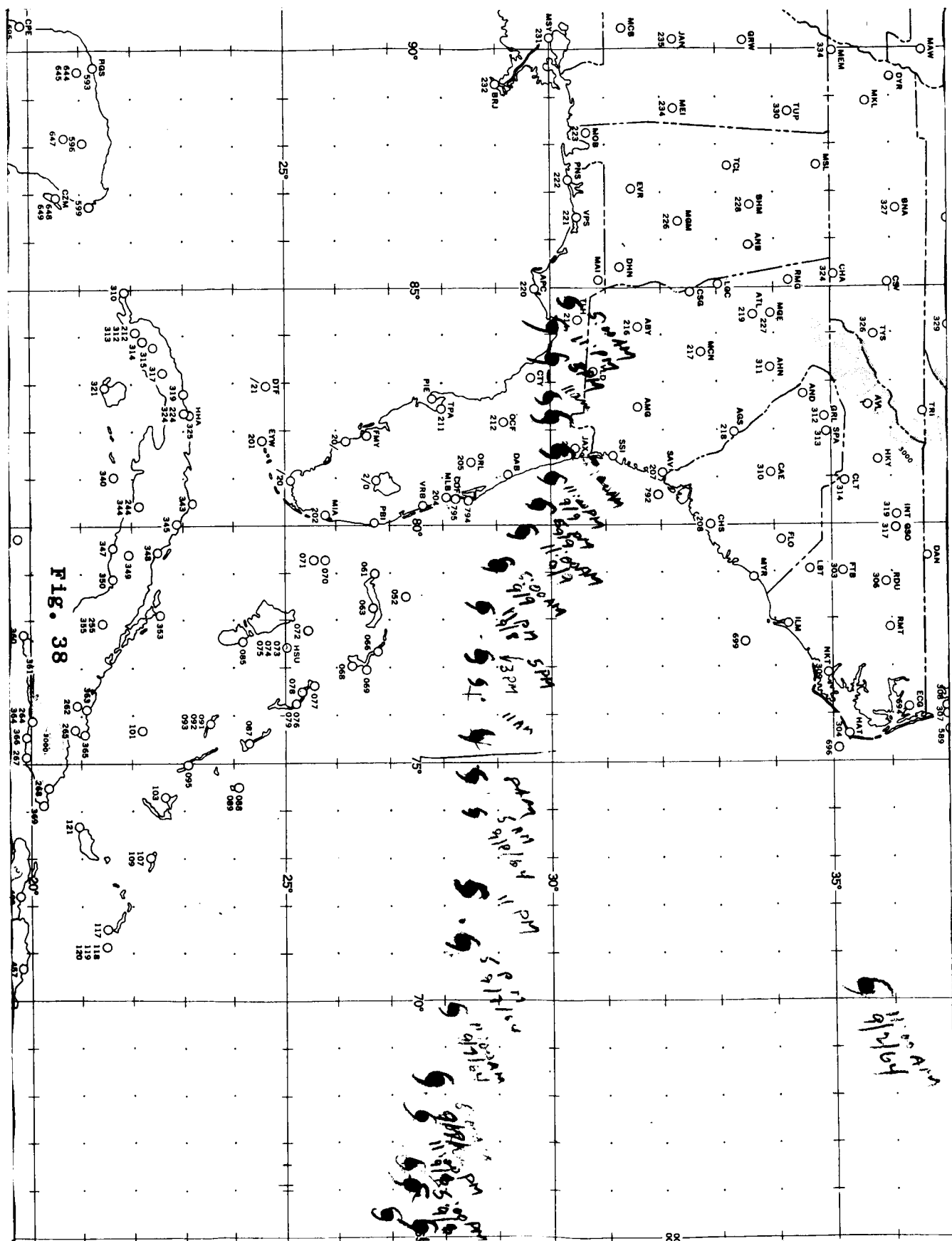
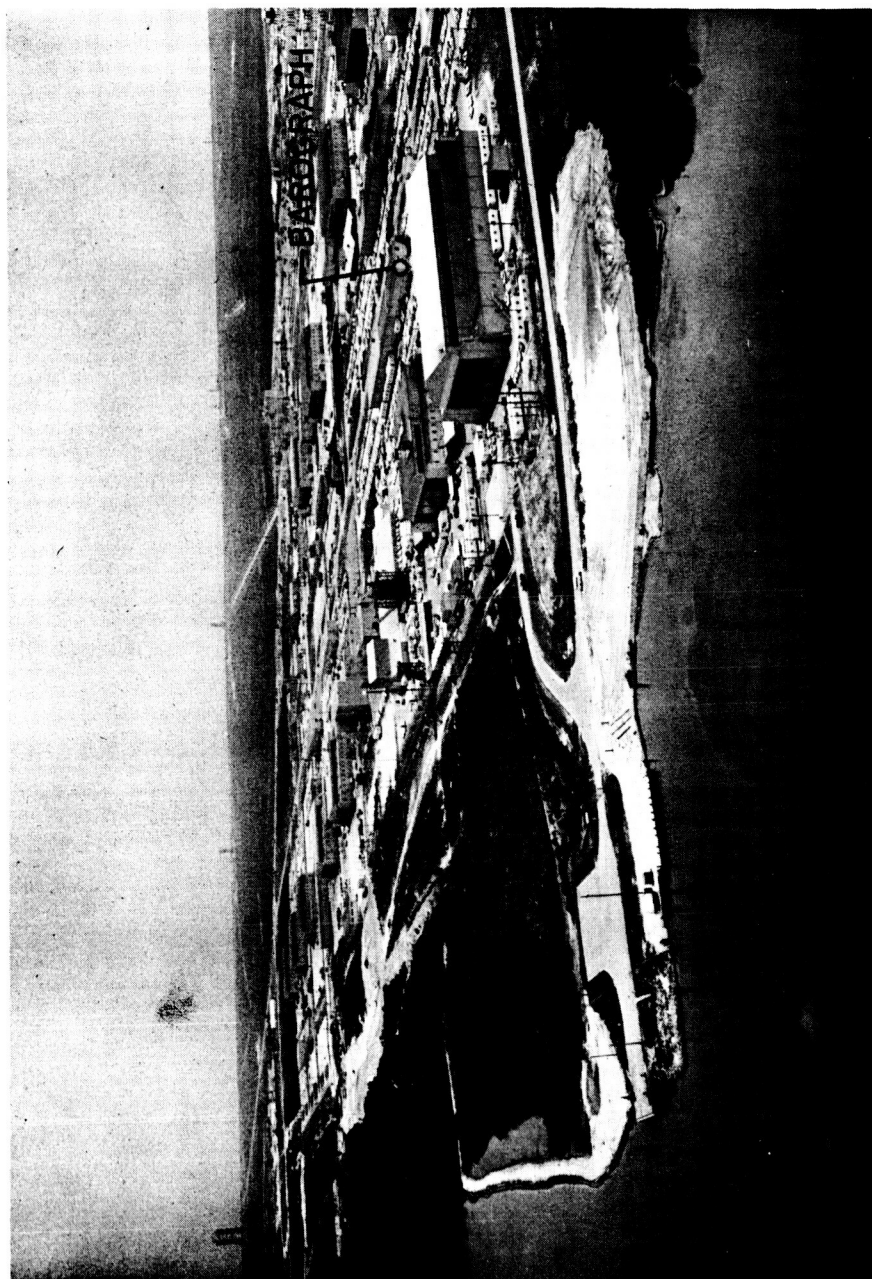


Fig. 37





Looking northeast over the industrial area.

FIGURE 40

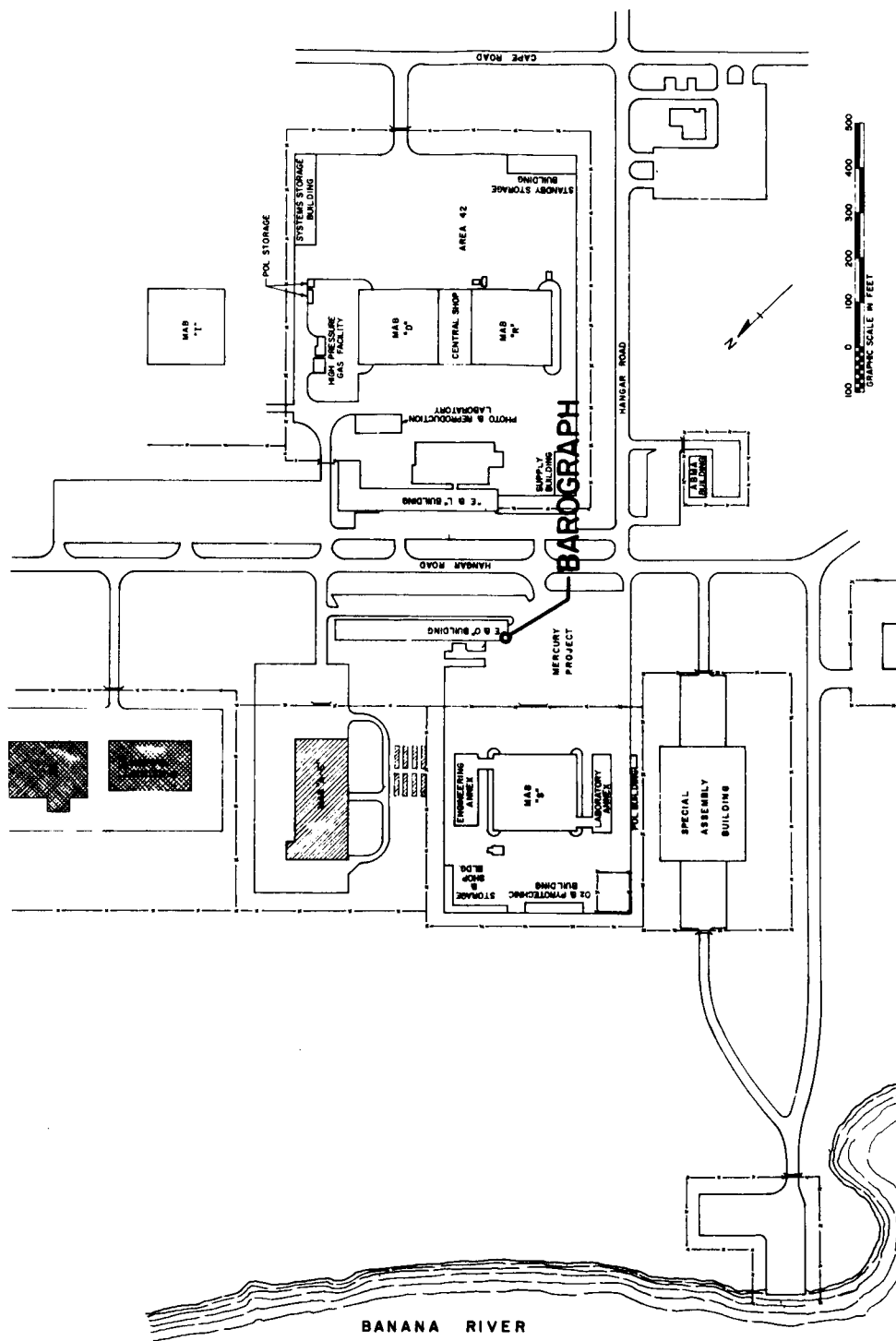
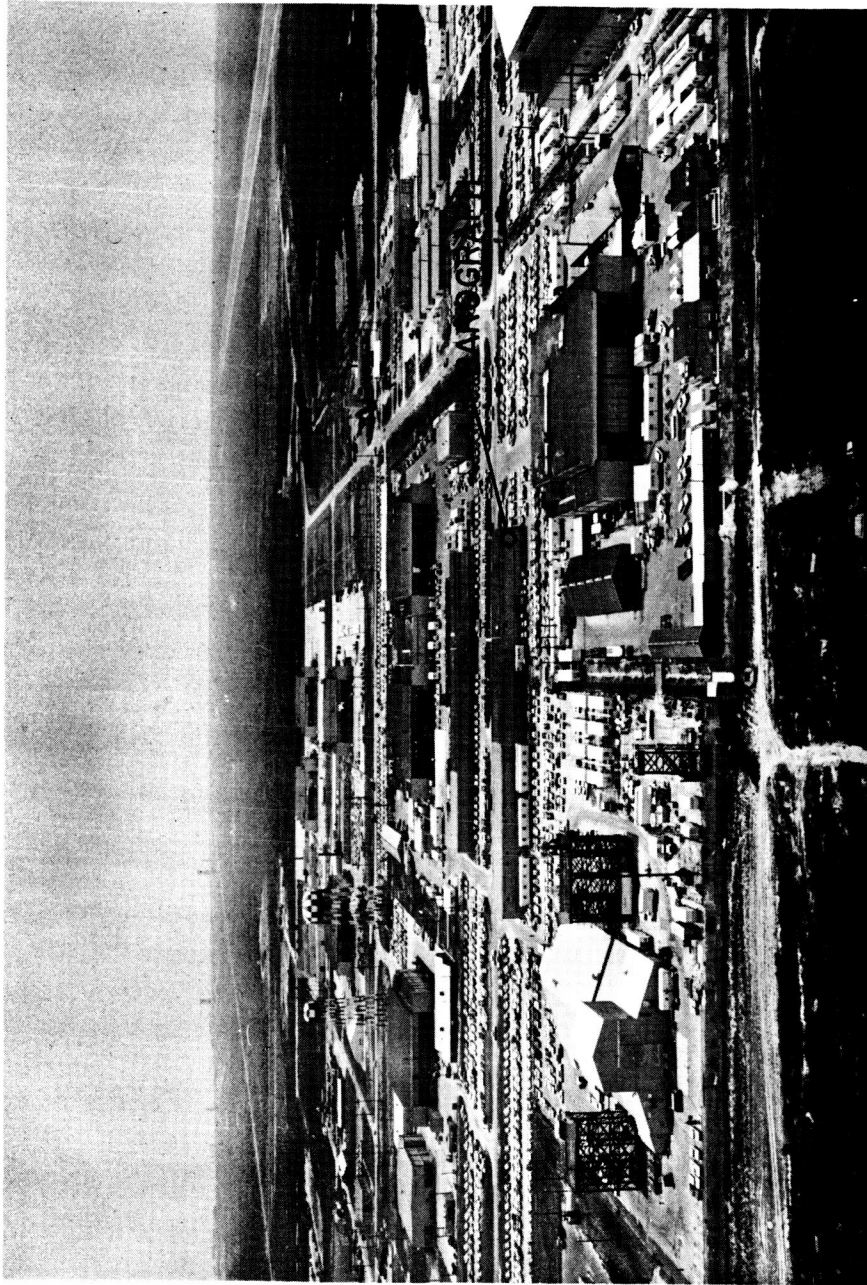


FIGURE 39



Looking east over the industrial area.

FIGURE 41

Cape Kennedy - 9/7/64
 E & O BLDG, 2nd Fl., SW Room
 DORA - ON 9-10 9/14/64

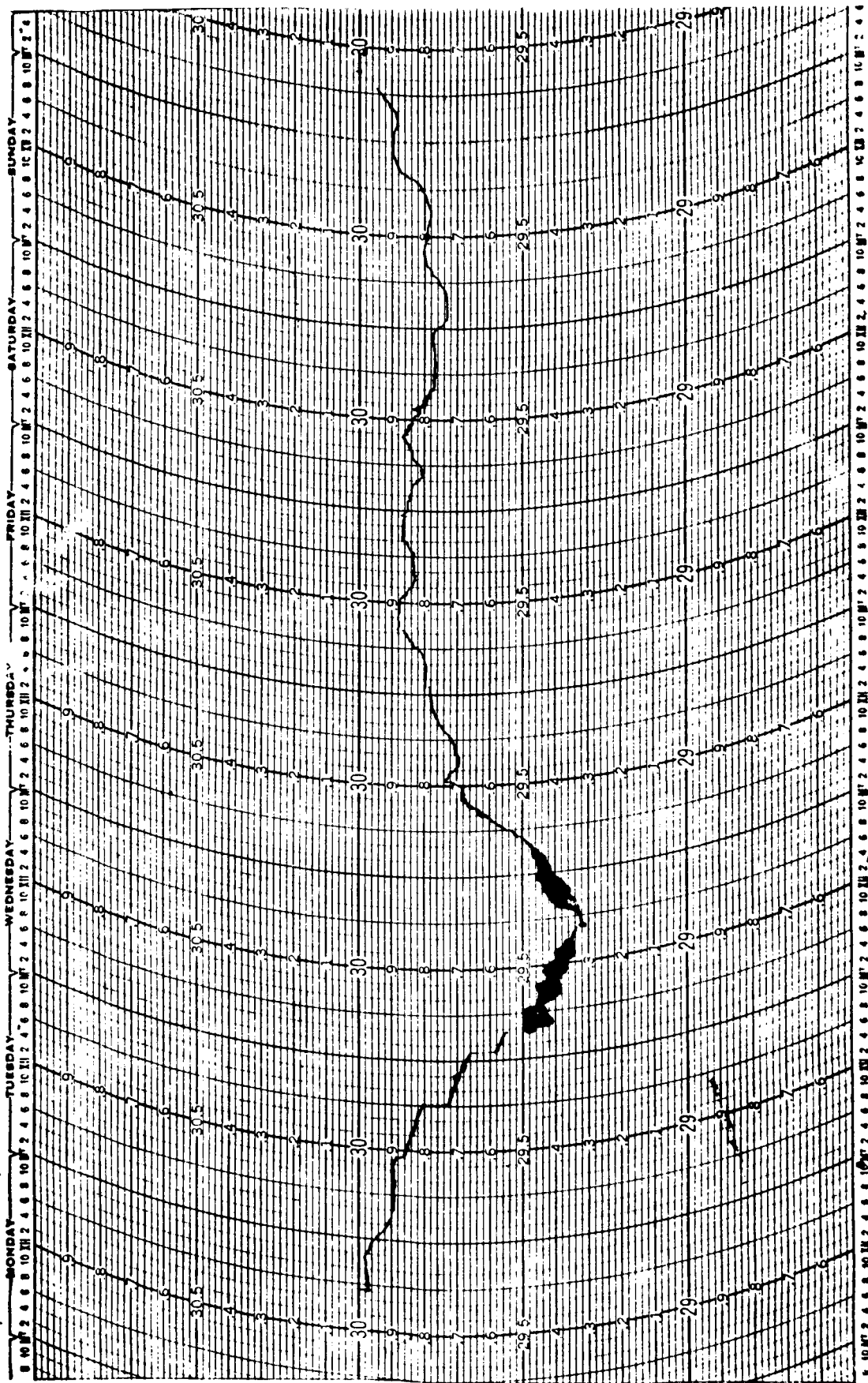


FIGURE 42

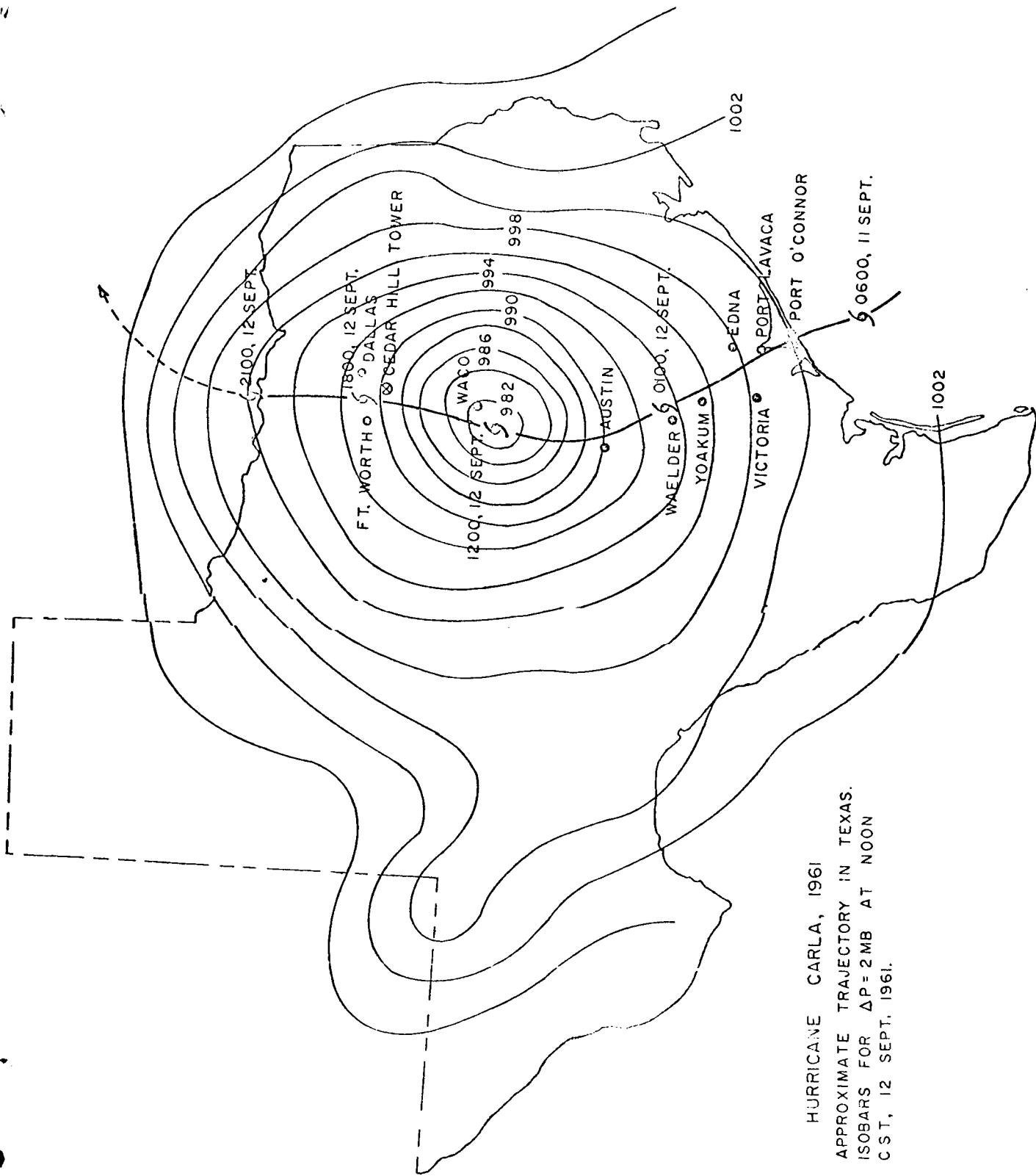
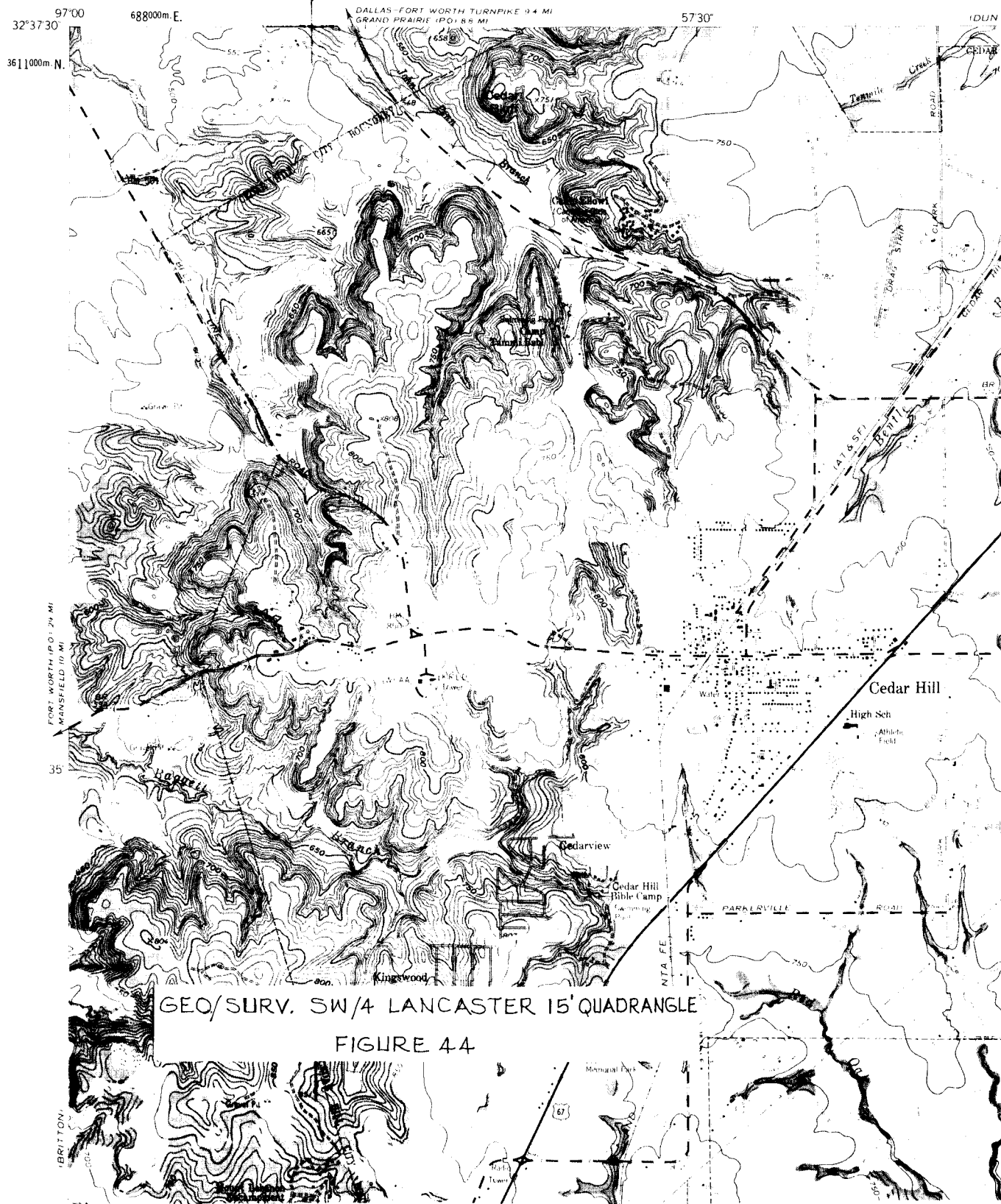


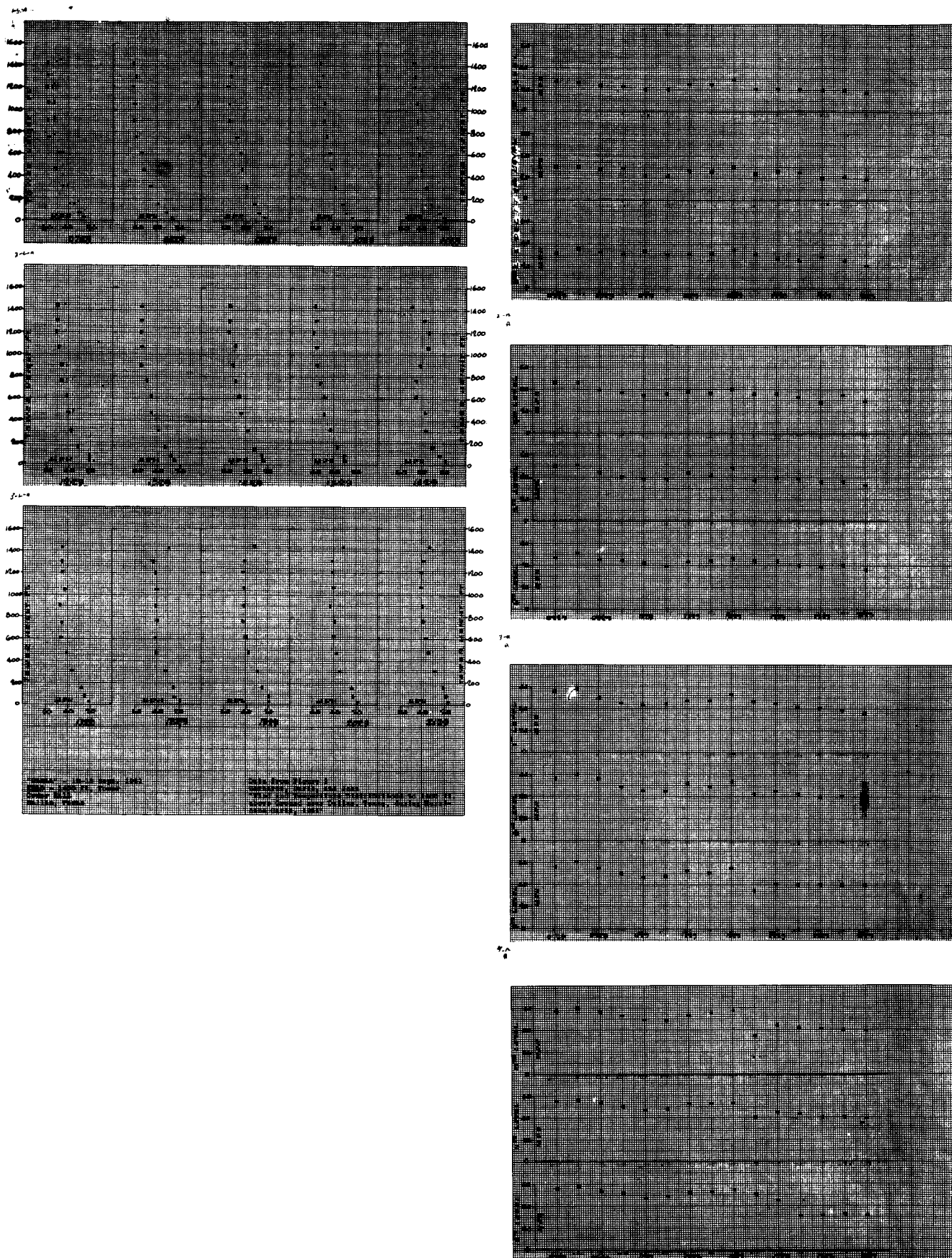
FIGURE 43

PATH of CARLA

ARLINGTON

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY





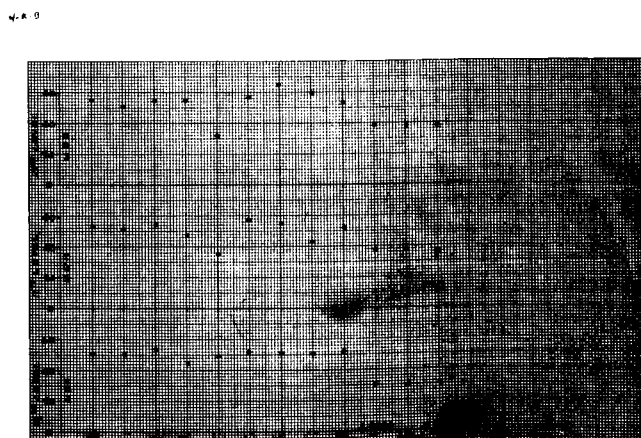
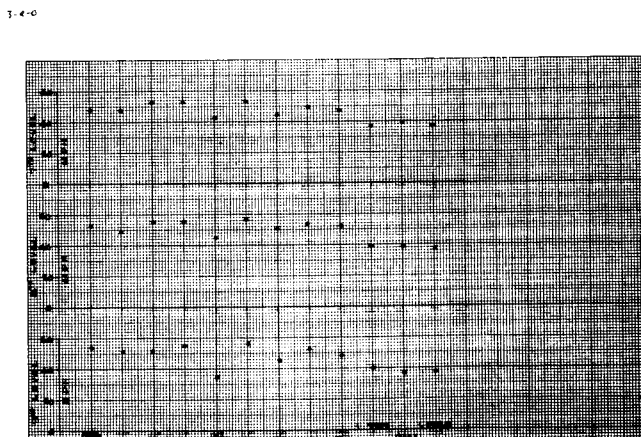
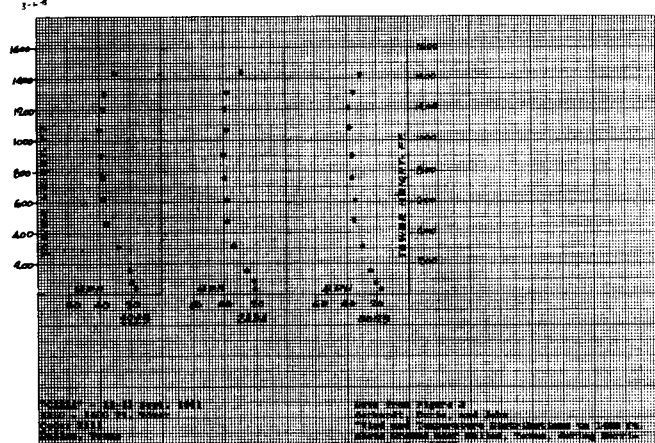
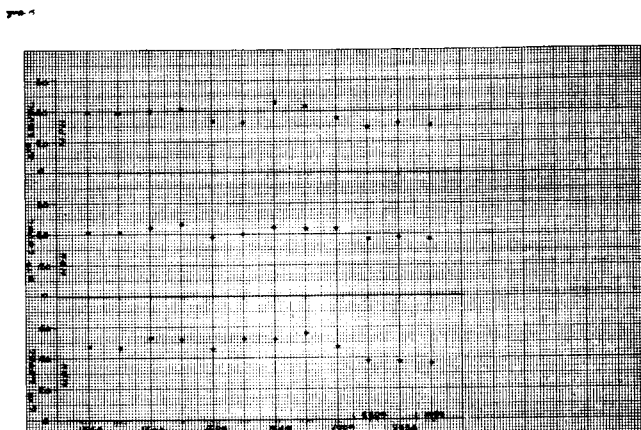
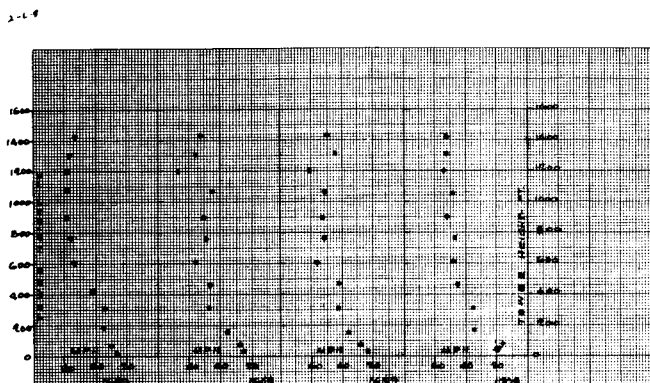
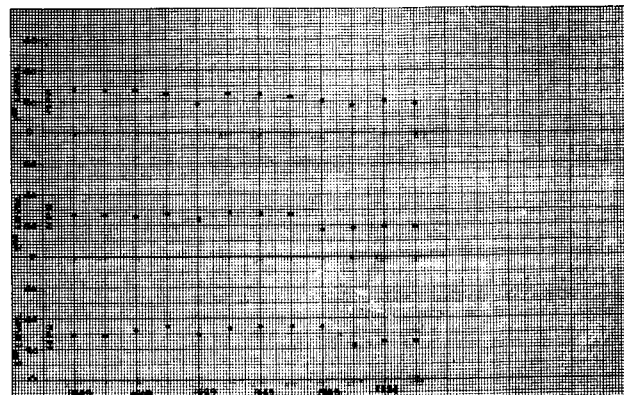
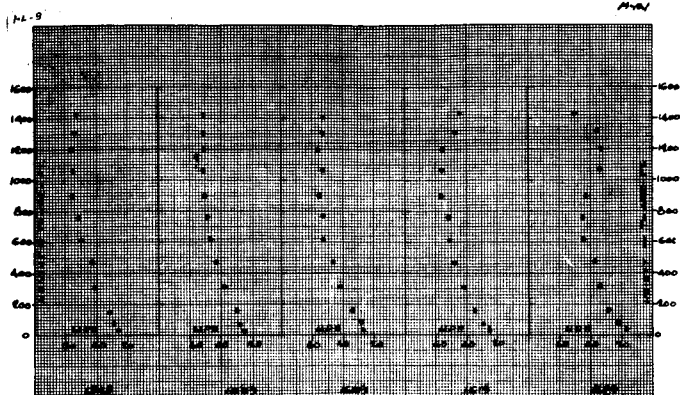


Fig. 46

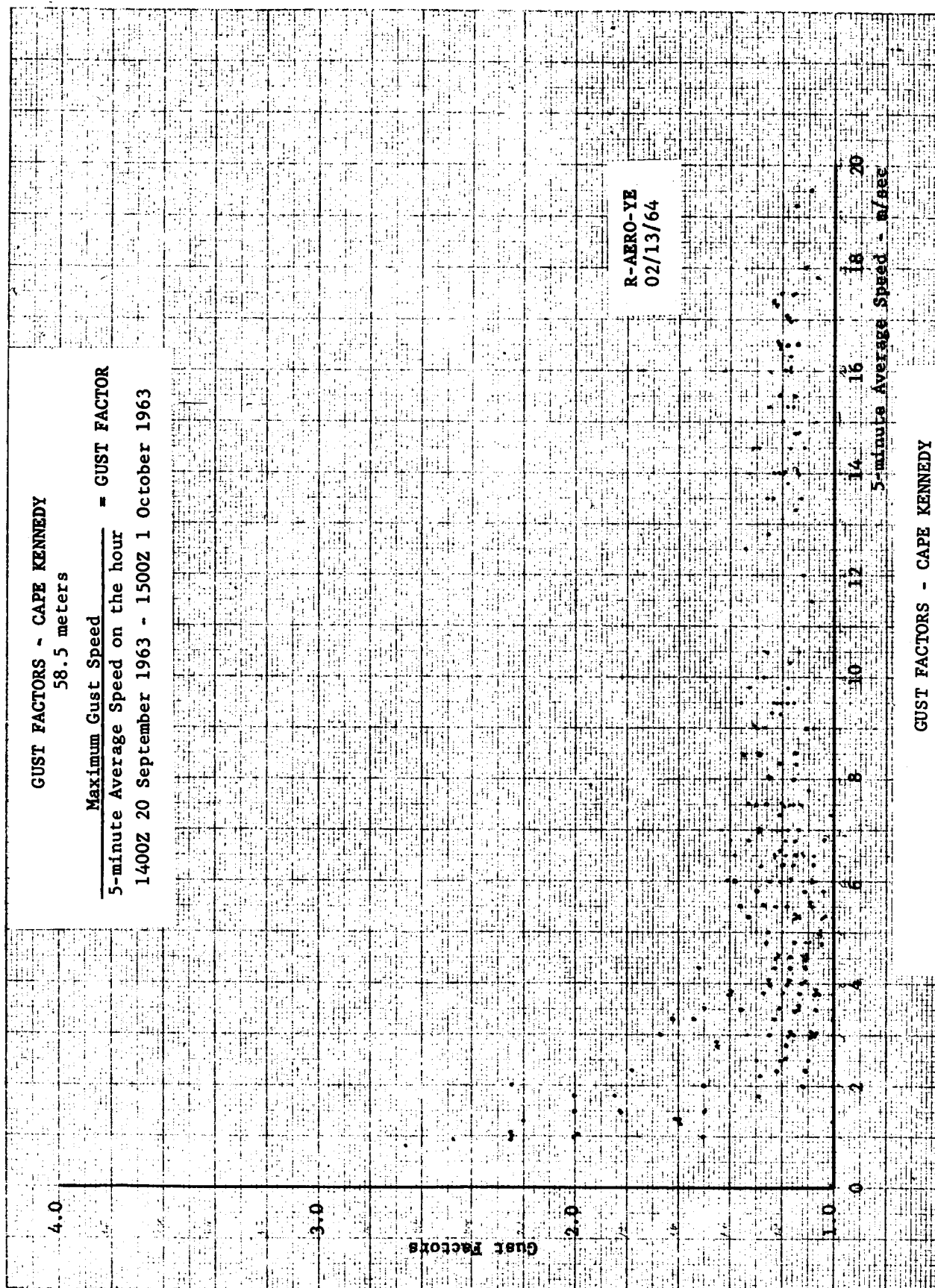


FIGURE 47

Fig. 47

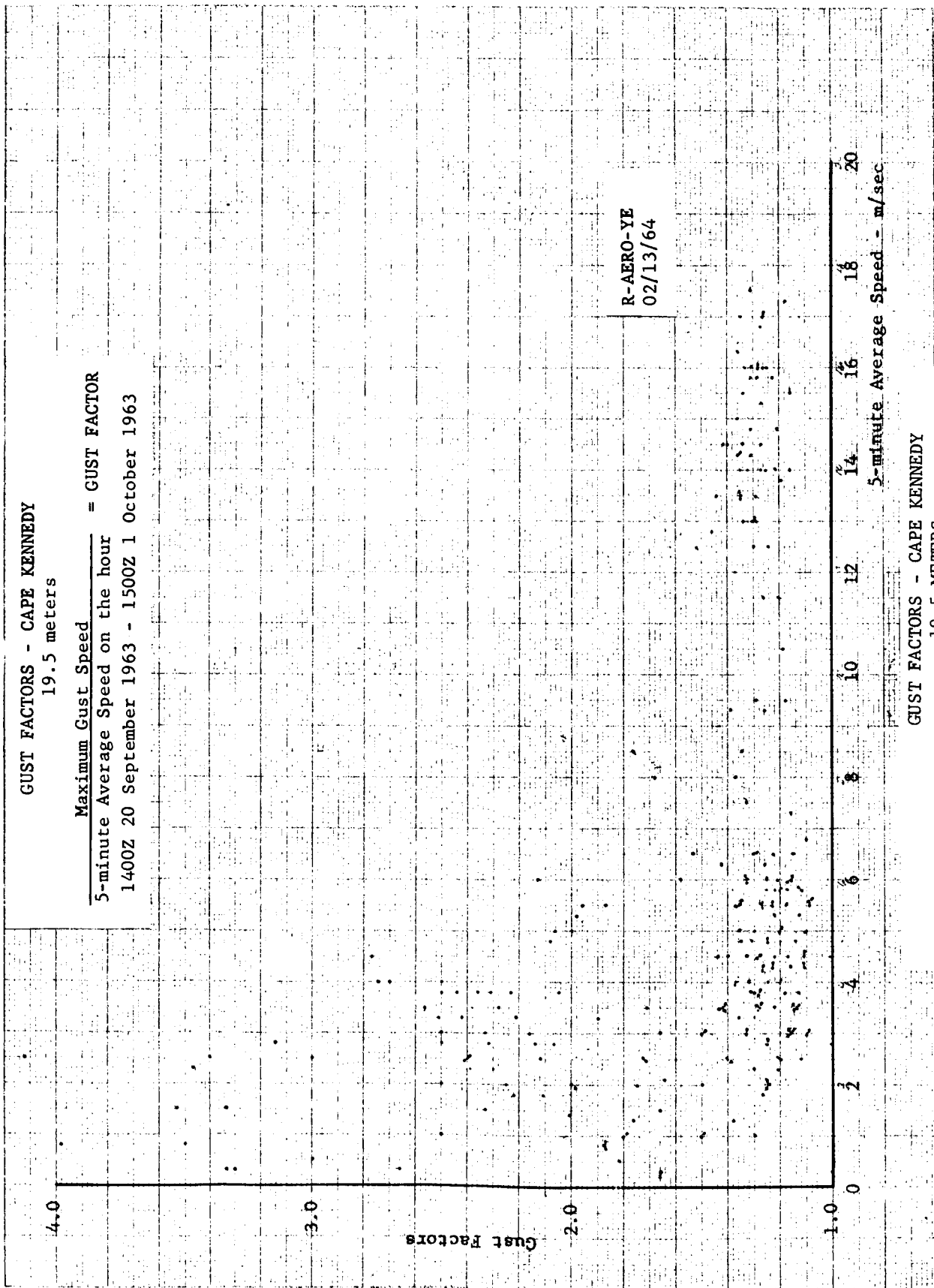


FIGURE 48

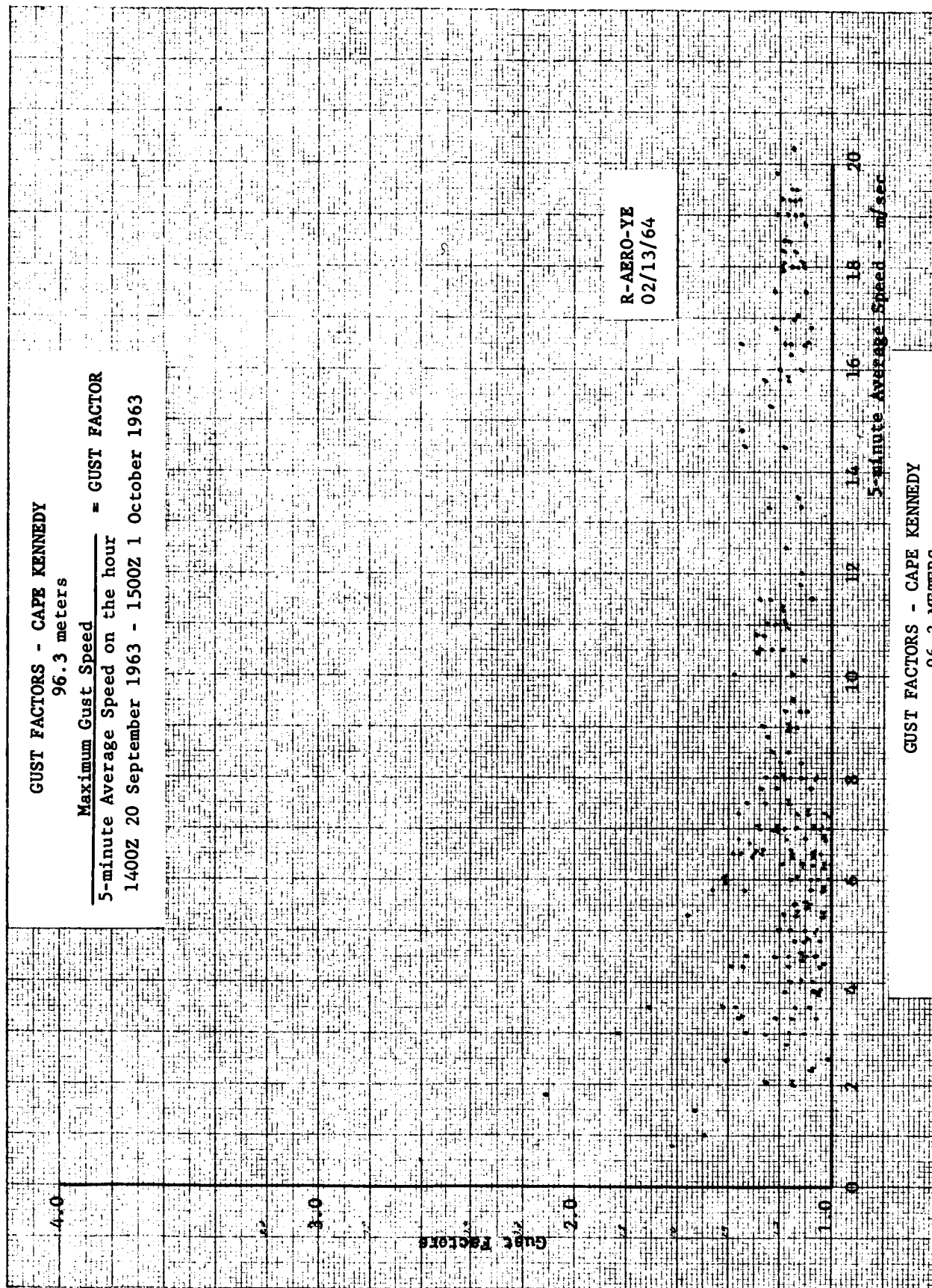


FIGURE 49

NORMALIZED VELOCITIES
FRONTAL PASSAGES AND HURRICANES
ONE-HOUR INTERVALS L.C. 34 AND L.C. 37
1964

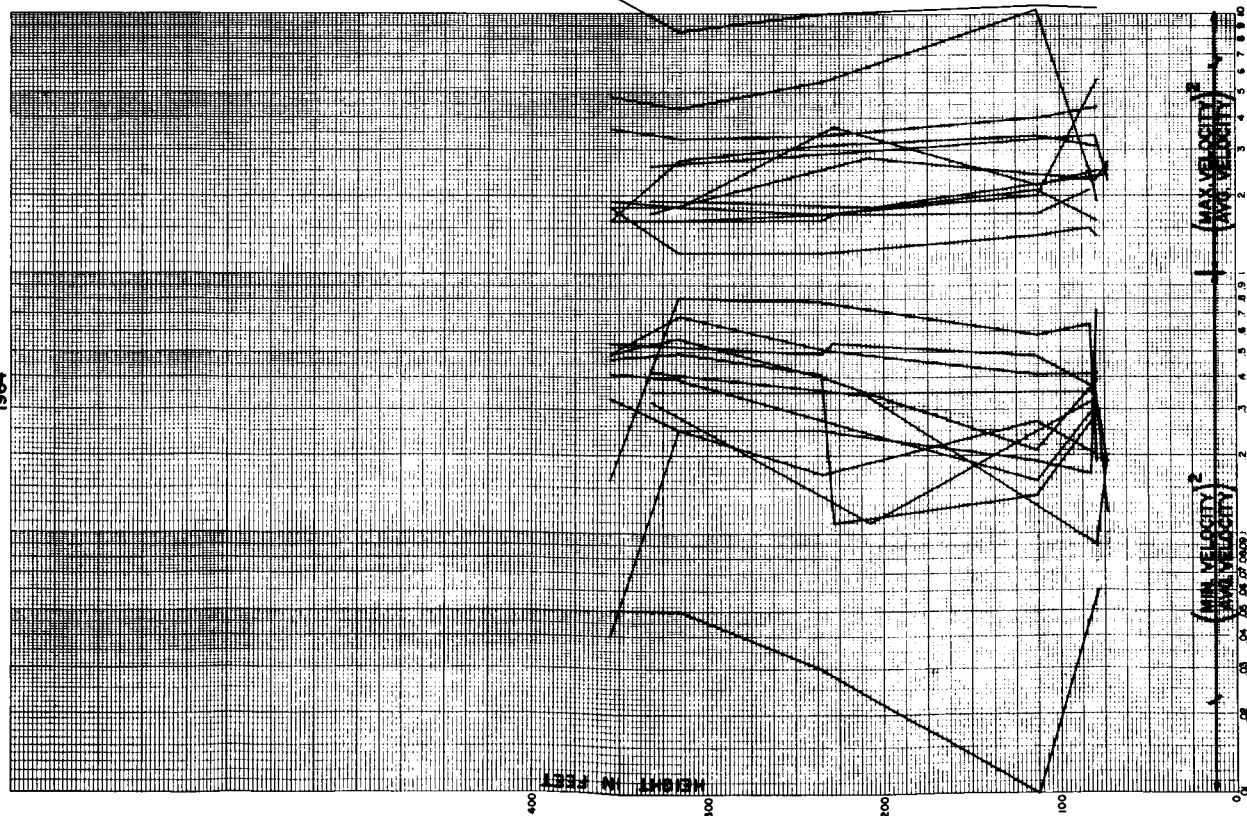


FIGURE 50

LINE SET

POINT SET

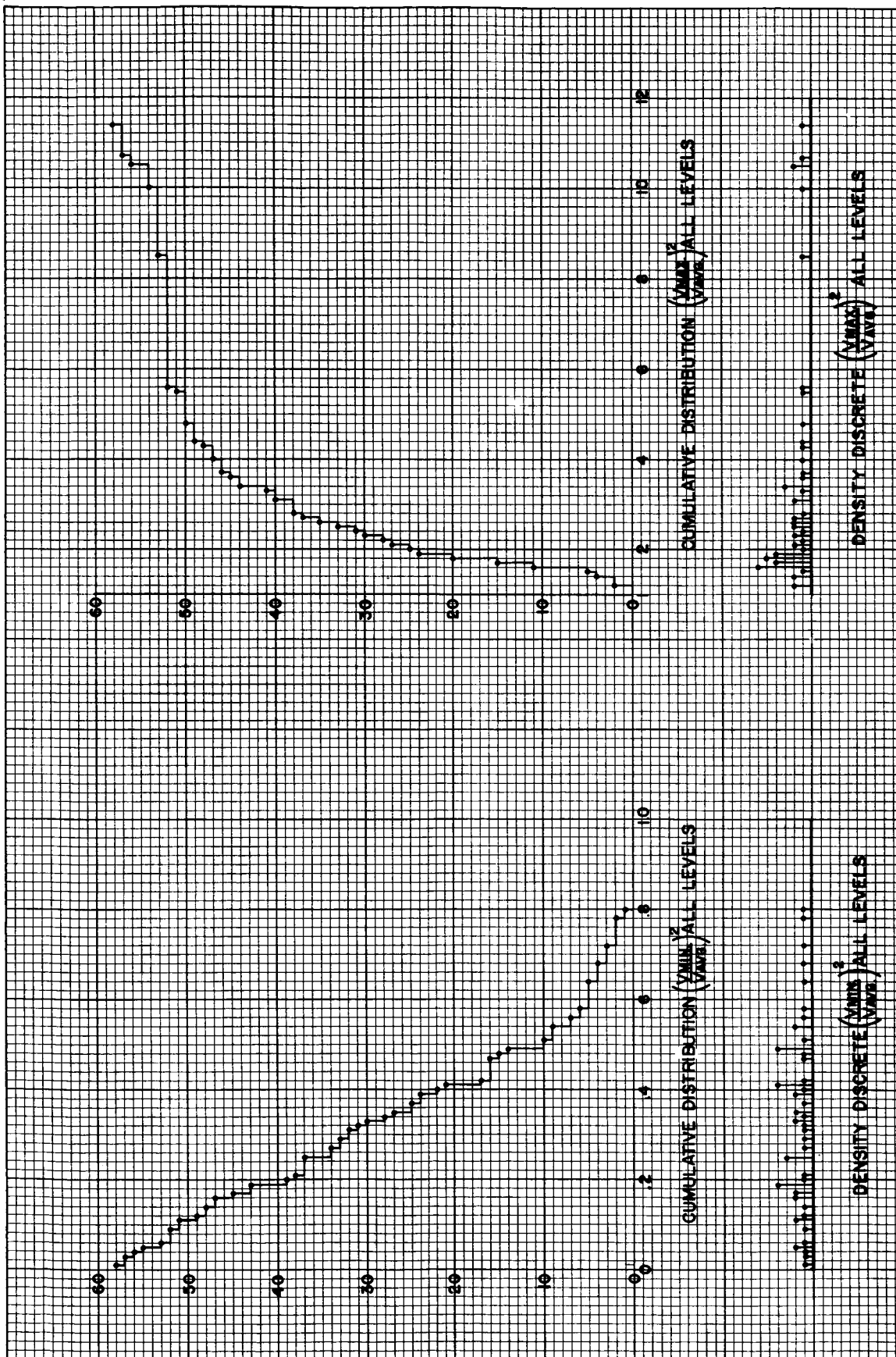


FIGURE 51

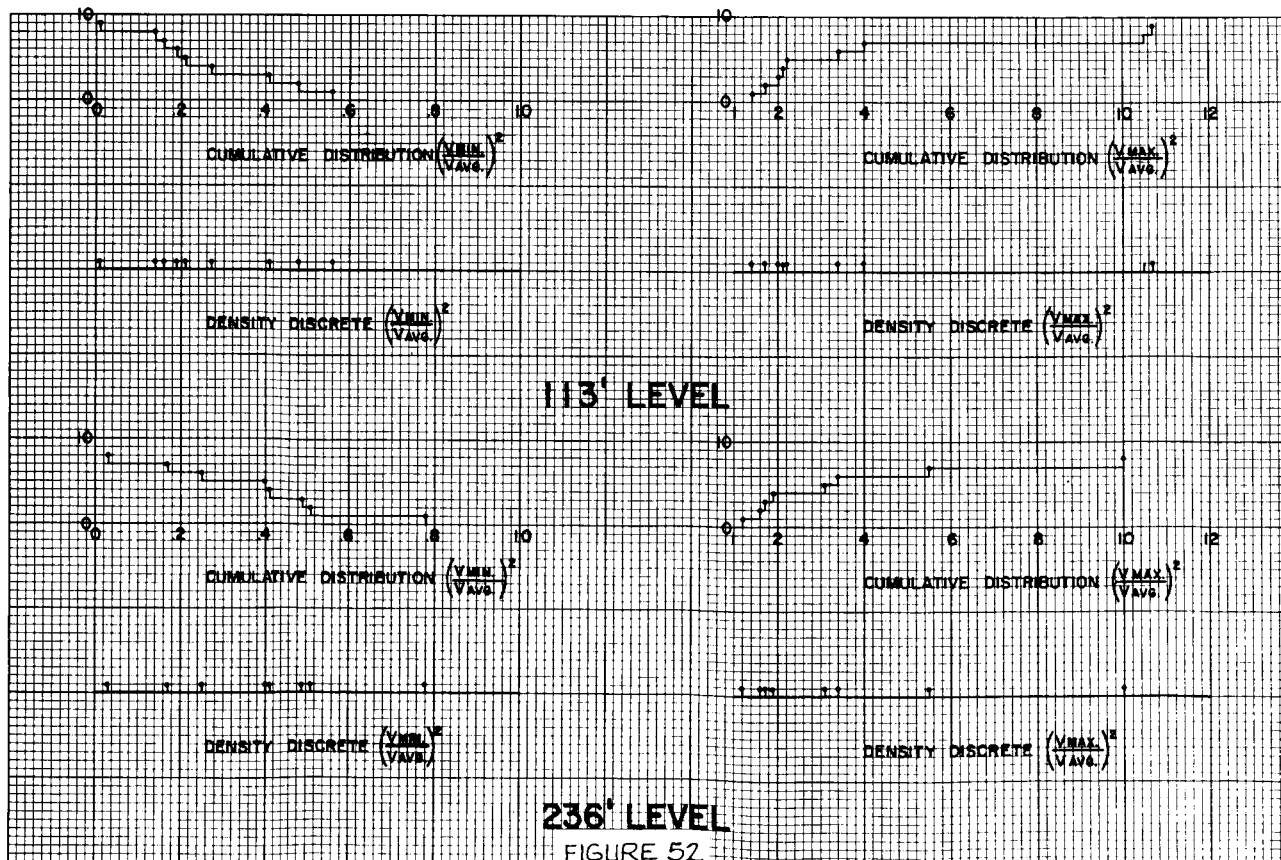
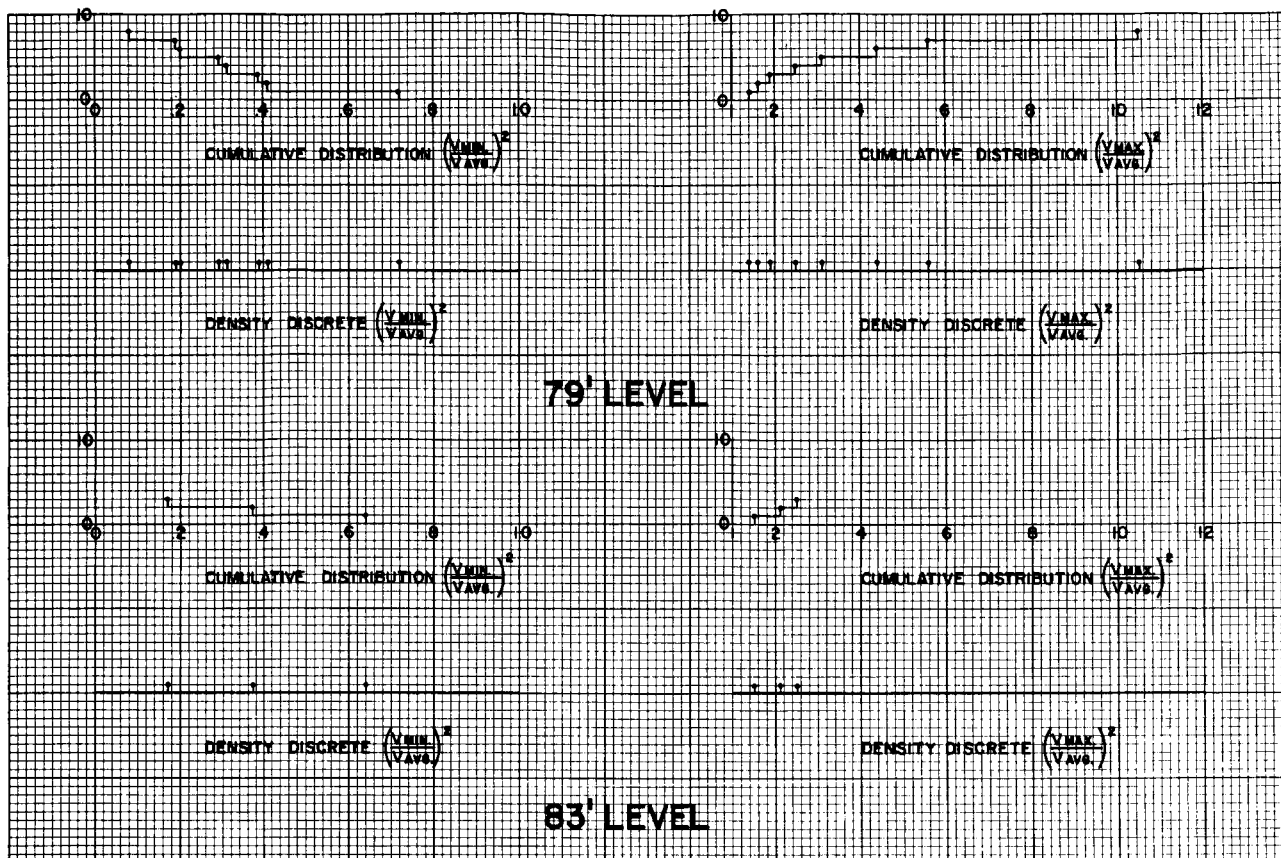
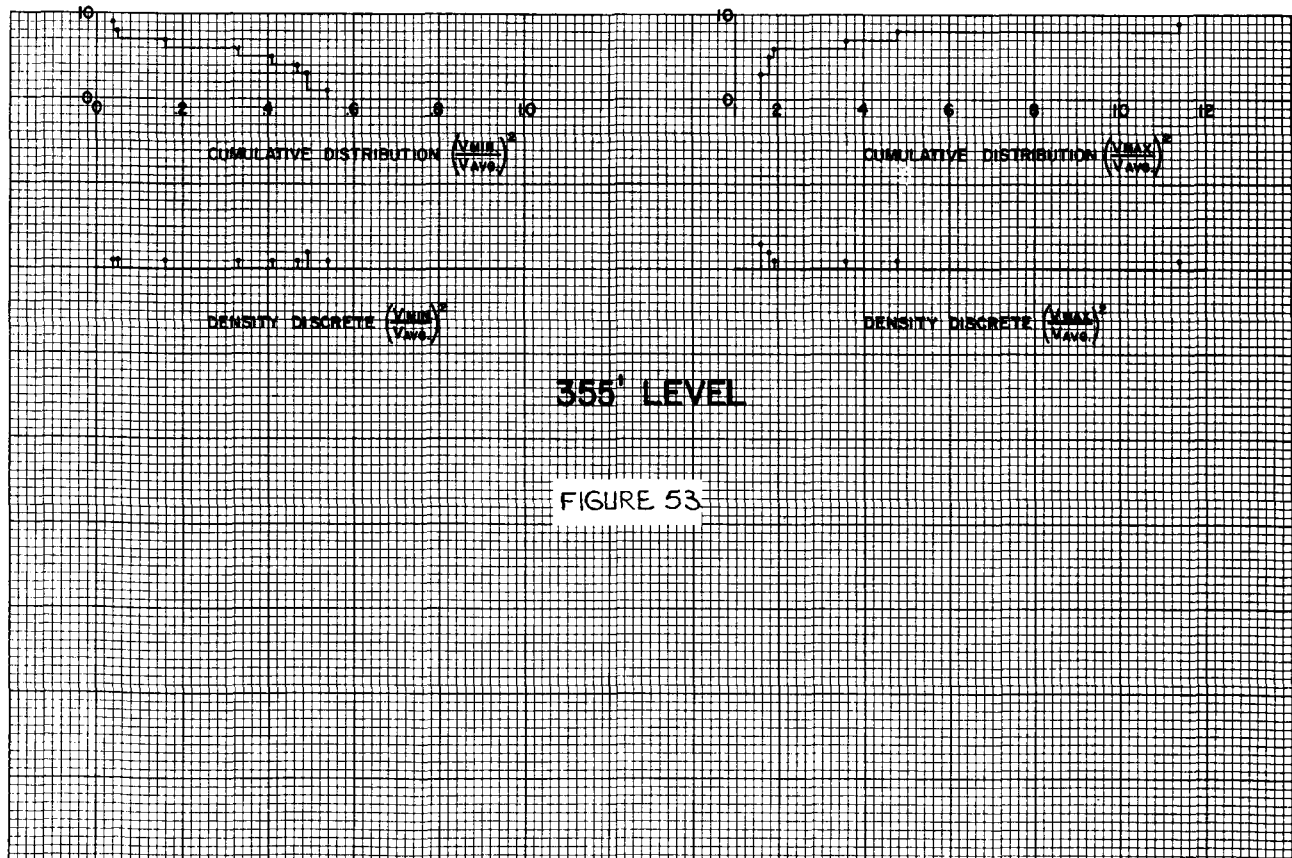
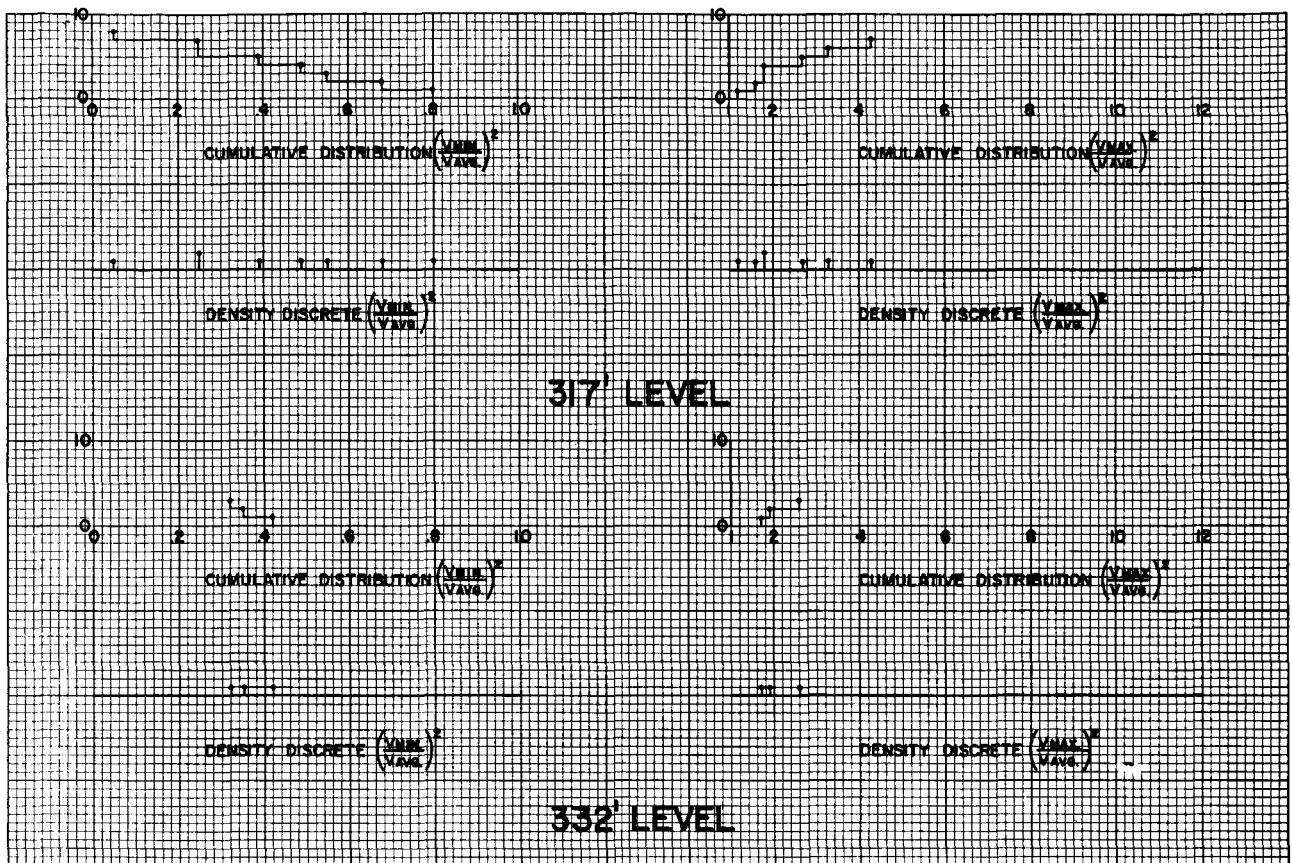


FIGURE 52



APPENDIX I.

LAMB DERIVATION, EKMAN SPIRAL

APPENDIX I

After "HYDRODYNAMICS"
by Horace LAMB

At any point on earth, not at a pole, assume z to be vertical positive in upward direction normal to surface; let axes x and y of vector field revolve with component (ω) about Oz of earth's angular velocity.

Assume steady motion, and putting $w = 0$, and neglecting horizontal gradients of u , and v , where $\bar{\nu} = \frac{\mu}{\rho}$ and where μ = average viscosity and ρ = average density then write

$$-2\omega v = -\frac{\partial p}{\rho \partial x} + \bar{\nu} \frac{\partial^2 u}{\partial z^2}$$

$$2\omega u = -\frac{\partial p}{\rho \partial y} + \bar{\nu} \frac{\partial^2 v}{\partial z^2}$$

$$0 = -\frac{\partial p}{\partial z} + \rho g$$

Assume uniform pressure gradient, then

$$-\frac{\partial p}{\rho \partial x} = 0, \quad -\frac{\partial p}{\rho \partial y} = f$$

Combining in imaginary vector field

$$\bar{\nu} \frac{\partial^2 (u+iv)}{\partial z^2} - 2i\omega (u+iv) = -if$$

$$\text{Let } \beta^2 = \frac{\omega}{\bar{\nu}}, \quad \frac{f}{2\omega} = V$$

At $z = \infty$, solution is

$$u+iv = V + Ce^{-(1+i)\beta z}$$

At $z=0$, let wind have angle α with x axis, then

$$u_0 + i v_0 = V_0 e^{i\alpha}$$

Assume tangential stress and velocity at ground are colinear, then

$$\frac{\partial u}{\partial z} / \frac{\partial v}{\partial z} = u/v \quad \text{at } z=0$$

and

$$u = V + e^{-\beta z} [V_0 \cos(\alpha - \beta z) - V \cos \beta z]$$

$$v = e^{-\beta z} [V_0 \sin(\alpha - \beta z) + V \sin \beta z]$$

At heights where gradient wind limits, $v=0$

then

$$\tan(\alpha - \beta z) = 1$$

After Berry, Bolay, and Beers, (Meteorology)

Solution is

$$\bar{u} + i \bar{v} = u_g [1 - e^{-(1+i)\alpha z}]$$

After Sutton,

$$\bar{V} = \bar{u} + i \bar{v} = G [1 - e^{-z \sqrt{\lambda/K}} (\cos z \sqrt{\lambda/K} - i \sin z \sqrt{\lambda/K})]$$

$K = \frac{A}{\rho}$ where A is interchange coefficient and K termed eddy viscosity.

$$\lambda = 2\omega \sin \phi,$$

APPENDIX II.

WIND MEASURING REACTION MACHINES

Appendix II

Wind Measuring REACTION MACHINES:

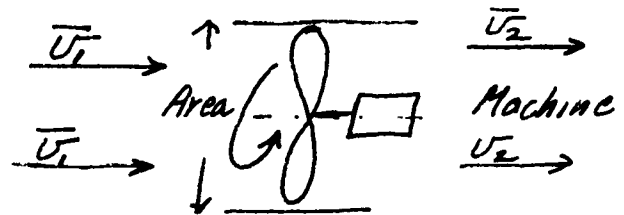
A. PITOT TUBE (frictionless) $p_{dynamic} = \frac{1}{2g} \rho v^2$

B. PROPELLER, AEROVANE $N_{rpm} \approx K_{Aero} v^2$

C. Cup Anemometer $N_{rpm} \approx K_{cups} v^2$

Any rotating device is a friction machine

Regardless of direction of discharge, power times time of action must equal kinetic Energy change



Let time of action be unit time

$F_{friction}$ is Force acting at distance L from center of rotation; N is rotational speed in rpm.

$$P \cdot t = 2\pi F \cdot L \cdot N \cdot t; t=1$$

$$\therefore \text{POWER} = F \cdot L \cdot N \cdot 2\pi$$

and

$$P \cdot t = KE_{in} - KE_{out}$$

$$\text{then } 2\pi F \cdot L \cdot N \cdot 1 = \frac{\text{Area} \cdot \rho \cdot v_1}{g} \left(\frac{v_{in}^2 - v_{out}^2}{2} \right)$$

Machine constants are Area, L , F , 2π , and g

Then

$$K_1 N = \frac{K_2}{2g} \cdot \rho \cdot v_1 (v_1^2 - v_2^2)$$

$$N = K \cdot \rho \cdot v_1 \frac{\Delta v^2}{\Delta t} \approx K \cdot \rho \cdot v_1 \frac{dv^2}{dt} \quad \text{if } \Delta v \text{ small.}$$

$$\text{Whence } N dt = K \cdot \rho \cdot 2 v_1^2 dv$$

Then, integrating from $t=0$ to $t=1$ and from v_2 to v_1

$$N \cdot t = K_{\text{Machine}} \cdot \rho \cdot (v_1^3 - v_2^3)$$

or in unit time

$$N \cdot 1 = N = K_{\text{Machine}} \cdot \rho \cdot (v_1^3 - v_2^3)$$

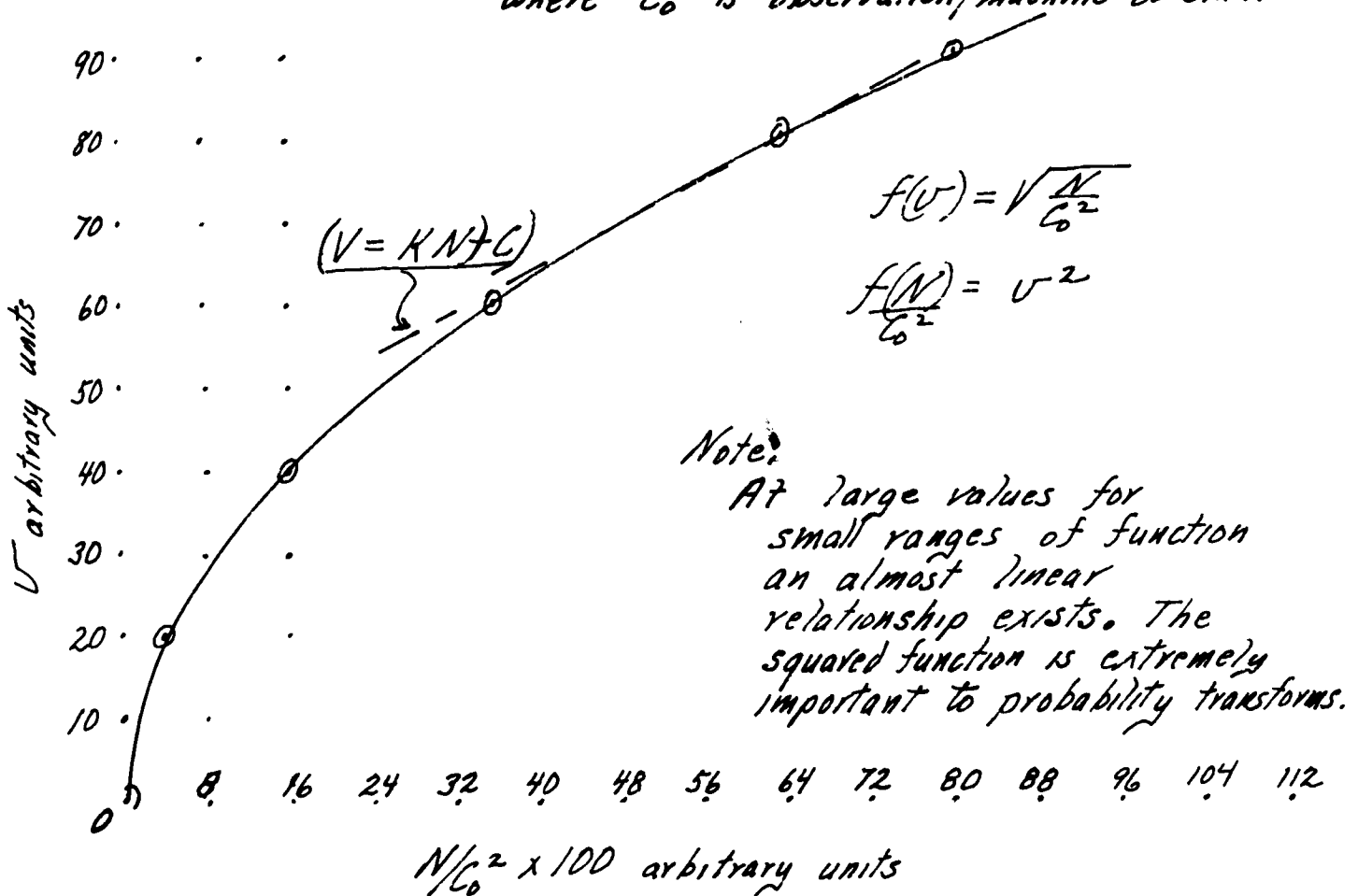
if $v_1 - \epsilon = v_2$ where ϵ is small compared to v_1 as is the case in real low friction machines

then $v_1^3 - (v_1 - \epsilon)^3 = 3\epsilon v_1^2 - 3\epsilon^2 v_1 + \epsilon^3 \approx 3\epsilon v_1^2$
since terms ϵ^2 and ϵ^3 will be of small magnitude

then

$$N \approx K_{\text{Machine}} \cdot \rho \cdot 3\epsilon v_1^2 = C_0^2 v^2$$

where C_0 is observation/machine constant

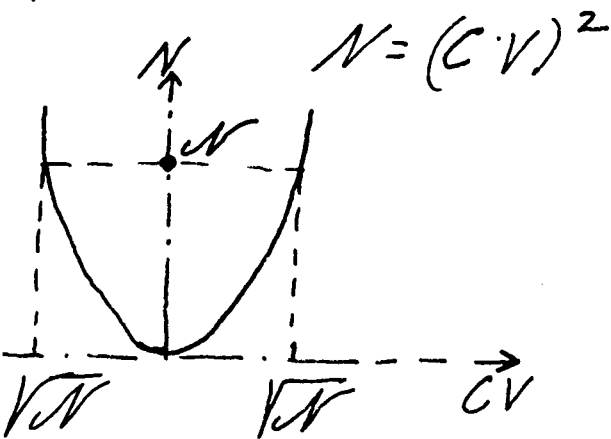


APPENDIX III

THE SQUARE LAW TRANSFORMATION

If $p_{\text{dynamic}} = K\rho V^2$ and $N_{\text{RPM}} = C_0^2 V^2 = K_{\text{mach}} \cdot \rho \cdot V^2$ then $\phi(p)$ may be linearly transformed into $\phi(N)$ and vice versa where ϕ is a probability function of either.

This is not true for transform of $\phi(p)$ or $\phi(N)$ into $\phi(V^2)$ or vice versa. Assume function



By examination, N can never be negative

$$\therefore P(N \leq N) = 0 ; N = 0$$

$$p_2(N) = 0 ; N < 0$$

Let $A(N)$ be set of points contained in $(-\sqrt{N} \leq CV \leq +\sqrt{N})$ when $N \geq 0$

$$\begin{aligned} \therefore P(N \leq N) &= P[-\sqrt{N} \leq CV \leq +\sqrt{N}] \\ &= P[CV \leq +\sqrt{N}] - P[CV < -\sqrt{N}] \end{aligned}$$

$$\text{HENCE } P(N \leq N) = \int_{-\infty}^{+\sqrt{N}} p_1(CV) d(CV) - \int_{-\infty}^{-\sqrt{N}} p_1(CV) d(CV)$$

Taking derivative of both sides with respect to N

$$p_2(N) = \frac{p_1(CV = +\sqrt{N}) + p_1(CV = -\sqrt{N})}{2\sqrt{N}} ; N \geq 0$$

APPENDIX III.

THE SQUARE LAW TRANSFORMATION

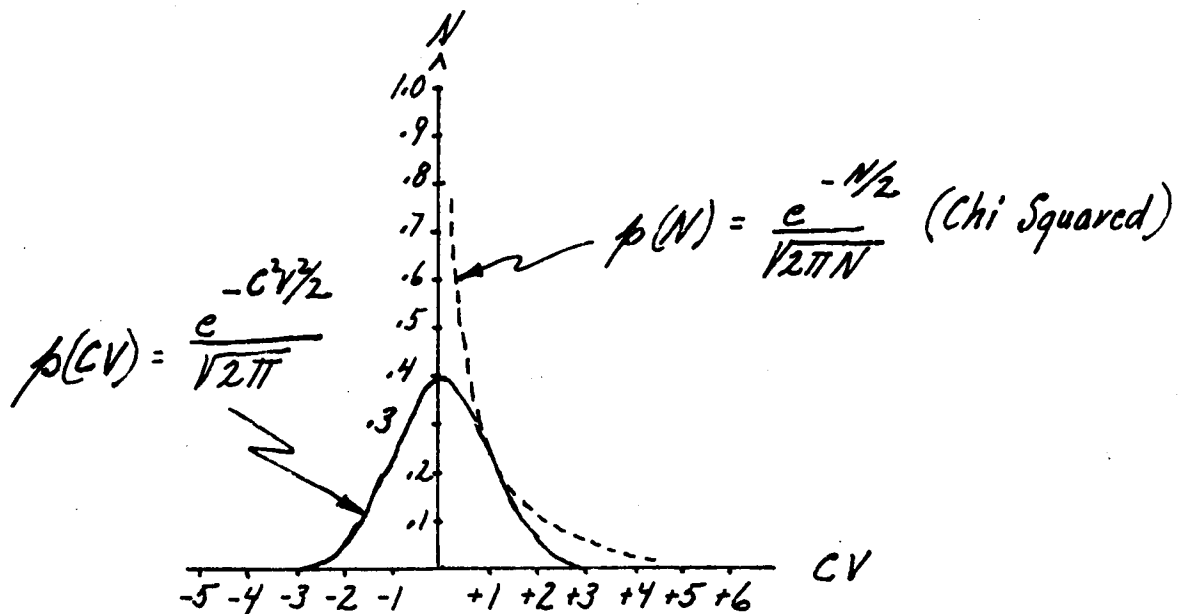
If form of $p(CV)$ is gaussian probability density

$$p(CV) = \frac{e^{-C^2V^2/2}}{\sqrt{2\pi}}$$

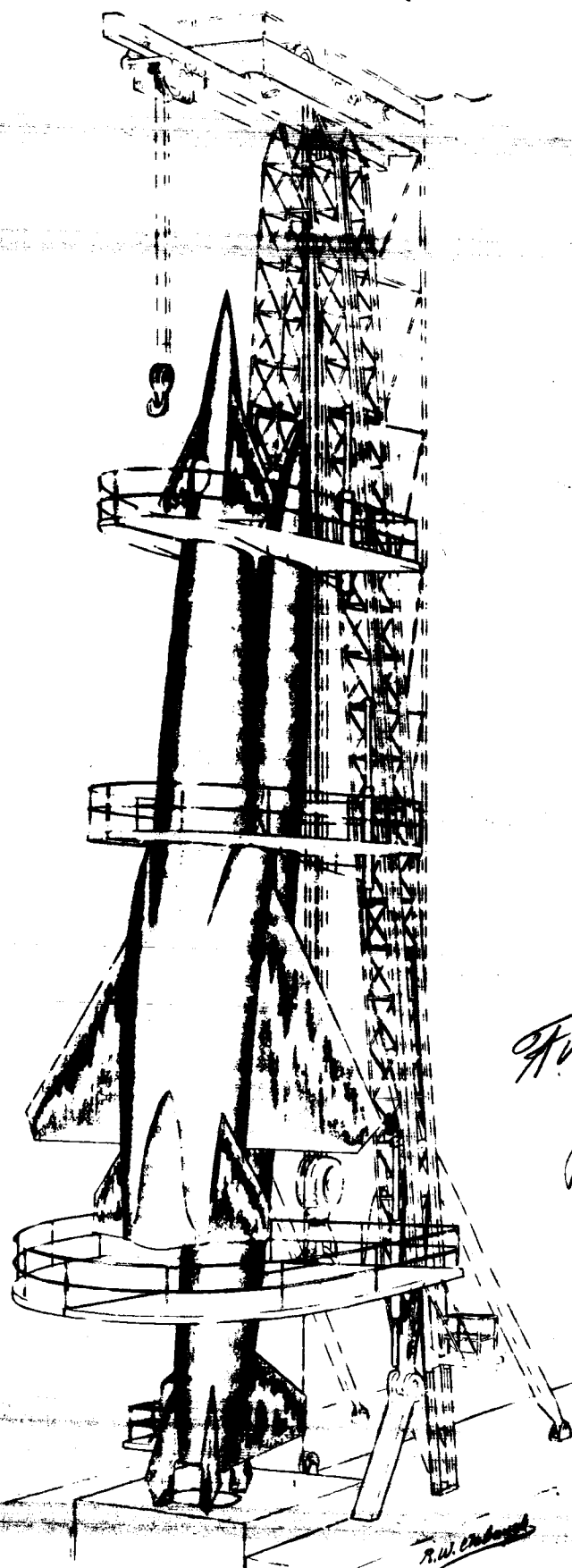
then

$$p(N) = \frac{e^{-N/2}}{\sqrt{2\pi N}} \quad ; \quad N \geq 0$$

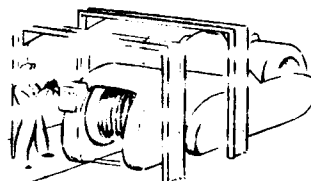
$$= 0 \quad ; \quad N < 0$$



COMPARISON OF GAUSSIAN AND CHI SQUARED
PROBABILITY DENSITY FUNCTIONS



First Concept
J. V. Durr



R.W. Anderson